Project Code/Version Number:
NGNGN05 – V02

Section 1. Project Summary

1.1 Project Title	H21 Phase 2 Network Operations – NIC		
1.2 Project Explanation	The project will build on Phase 1 to provide the next stage of quantified safety-based evidence to confirm the gas distribution networks of GB are suitable to transport 100% hydrogen. The evidence produced will be used to support the case for a GB hydrogen conversion which could represent the biggest single contribution to the Climate Change Act and the new Net Zero target now enshrined in law.		
1.3 Funding licensee:	Northern Gas Networks		
1.4 Project description:	*1.4.1 The Problem(s) it is exploring* Can we manage the network and the conversion to 100% hydrogen process safely. There is a need to confirm we can operate and manage the 100% hydrogen network safely through an appraisal of network components, procedures, network modelling and testing *1.4.2 The Method(s) that it will use to solve the Problem(s)* Review, test and make recommendations to amend the operational and maintenance procedures required to operate a network on 100% hydrogen. Trial network operations and network modelling on new purpose built micro-grid before trials on an existing unoccupied network *1.4.3 The Solution(s) it is looking to reach by applying the Method(s)* Provide further evidence towards the safety case to convert the GB network from natural gas to 100% hydrogen which will complement the BEIS Hy4Heat project and support other industry research, providing the safety-based evidence required to progress a credible policy decision on heat. *1.4.4 The Benefit(s) of the project* Provides further evidence to confirm the suitability of converting the GB gas network to 100% hydrogen.		
1.5 Funding			
1.5.1 NIC Funding Request (£k)	6,801	*1.5.2 Network Licensee Compulsory Contribution (£k)*	761
1.5.3 Network Licensee Extra Contribution (£k)	0	*1.5.4 External Funding – excluding from NICs (£k):*	225
1.5.5 Total Project Costs (£k)	7,839		

1.6 List of Project Partners, External Funders and Project Supporters (and value of contribution)	Project Partners: Cadent Gas, SGN, Wales & West Utilities, National Grid, Health and Safety Executive Science Division (HSE-SD) and DNV GL. External Funders: DNV GL - £225k Project Supporters: ENA, HHIC, Cadent Gas, TVCA, IGEM, National Grid, Project Rome, Netbeheer Nederland, AusNet Services, Arup, Energy Networks Australia, Leeds City Council and AGN. Also see Appendix J: Letters of Support		
1.7 Timescale			
1.7.1 Project Start Date	January 2020	*1.7.2 Project End Date*	December 2021
1.8 1.8. Project Manager Contact Details			
1.8.1 Contact Name & Job Title	Tim Harwood	*1.8.2 Email & Telephone Number*	tharwood@northerngas.co.uk 07880 007 365
1.8.3 Contact Address	Northern Gas Networks, 1100 Century Way, Thorpe Park Business Park, Colton, Leeds, LS15 8TU		
1.9 Cross Sector Projects (only complete this section if your project is a Cross Sector Project, i.e. involves both the Gas and Electricity NICs).			
1.9.1 Funding requested the from the [Gas/Electricity] NIC (£k, please state which other competition)	N/A		
1.9.2 Please confirm whether or not this [Gas/Electricity] NIC Project could proceed in the absence of funding being awarded for the other Project.	N/A		
1.10 Technology Readiness Level (TRL)			
1.10.1 TRL at Project Start Date	5	*1.10.2 TRL at Project End Date*	8

Section 2. Project Description

2.0 Executive Summary

The current GB gas distribution network transports natural gas (predominantly methane CH_4) which is burnt in customers' properties across the country producing carbon dioxide, water and heat. Hydrogen (H_2) when burnt only produces water and heat and therefore a conversion of the GB gas distribution networks to hydrogen would provide customers with all the benefits of the gas networks without the carbon footprint.

The objective of the H21 programme is to reach the point whereby it is feasible to convert the existing natural gas network to 100% hydrogen and provide a contribution to decarbonising GBs heat and power sectors with the focus on finding a green alternative to natural gas.

The H21 programme builds on the work of the 2016 H21 Leeds City Gate (LCG)[1] and the 2018 North of England (NoE) project[2], which established hydrogen conversion is technically possible and economically viable. The H21 programme will provide essential evidence to support the Government's £25 million 'Downstream of the ECV' hydrogen programme (Hy4Heat), which examines using hydrogen as a potential heat source in the home. This next phase of the H21 programme continues to be a collaborative bid involving all the GB Gas Distribution Networks (GDNs) and now National Grid.

The aim of the H21 Phase 2 project is to provide safety critical evidence to support the viability of a 100% hydrogen live community trial by:

- Appraising and demonstrating the current network operation and maintenance procedures for use with 100% hydrogen.
- Undertaking unoccupied network trials.
- Combining the H21 and Hy4Heat QRAs for an end-to-end QRA for 100% hydrogen.
- Develop a range of language and educational materials that will support customer engagement, understanding and acceptance of the benefit of change to hydrogen and lead to a positive customer experience overall.

2.1 Aims and objectives

2.1.1 The Problem(s) which needs to be resolved

The UK was legally bound to make ambitious carbon reductions under the terms of the Climate Change Act (2008). However, the UK government signed legislation on 27th June 2019[3] committing the UK to a legally binding target of Net Zero emissions by 2050. This means the UK must tackle decarbonisation at pace and change the way energy is produced, transported and consumed to meet this new target.

In 2017, 48%[4] of the UK's electricity generated was supplied by fossil-fuels (41% natural gas, 7% coal). Natural gas dominates the heat supply curve, heating 85%[5] of UK households in 2017. Excluding transport, natural gas provided more than 50%[6] of total UK energy consumption in 2017. Heat demand is highly variable, and, compared with alternatives such as heat pumps, natural gas is readily capable of meeting peak heat demand. Therefore, there is a huge focus on finding a green alternative to natural gas. Delivering low carbon heat via existing GB gas infrastructure capitalises on existing network assets cost effectively and means that customers do not require disruptive and expensive changes in their homes. In the recent Committee on Climate Change (CCC)

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1 H21 Leeds City Gate report, July 2016
2 H21 North of England Report - 2018
3 News Article - UK becomes first major economy to pass net zero emissions law
4 Committee on Climate Change - Net Zero Technical Report - May 2019
5 IET - Transitioning to hydrogen report 2019
6 BEIS - ECUK Tables - Table C1

progress report[7] to Parliament, they reported an expectation of large scale hydrogen trials to begin within the next year and were critical of progress with CCS and stated **"no large-scale trials have yet begun for heat pumps or low-carbon hydrogen. Development of these markets and of a skilled workforce needs to go hand-in-hand but there have been no serious steps towards their development, in buildings, industry or (for hydrogen) transport".** The National Infrastructure Commission's, National Infrastructure Assessment[8] recommends that government needs to make progress towards zero carbon heat by:

- Establishing the safety case for using hydrogen as a replacement for natural gas, followed by trialling hydrogen at community scale by 2021
- Subject to the success of community trials, launching a trial to supply hydrogen to at least 10,000 homes by 2023, including hydrogen production with carbon capture and storage.

H21 Phase 2 is an important stepping stone, providing evidence that would underpin any future move towards a community trial, in line with the preliminary work being undertaken by Hy4Heat. It would also be the first stage preparing to train skilled workers in the conversion, operation and maintenance of a hydrogen network.

Converting the GB gas networks to 100% hydrogen has the potential to provide a significant contribution to decarbonisation and the UK Net Zero target. The safety-based evidence for a conversion to 100% hydrogen transported through the existing gas distribution networks and then utilised within buildings needs to be provided before the viability of the option can be confirmed. A credible government policy decision on decarbonisation of heat will not be possible without this critical information.

Whilst the benefits of such a conversion, in the context of climate change, are undeniable, there remain some essential evidence gaps which must be closed before a policy decision can be made. The aim of the H21 programme is to reach the point whereby it is feasible to convert the existing natural gas network to 100% hydrogen and thus providing a contribution to decarbonising GBs heat, transport and power sectors with the focus on finding a green alternative to natural gas.

2.1.2 The Method(s) being trialled to solve the Problem

The H21 programme is the only project in the UK currently looking at the possibility of converting the existing metallic and PE gas network system 'upstream of the Emergency Control Valve (ECV)' to 100% hydrogen. It is significantly important as it will allow the re-use of the full existing gas network, identifying the component parts of the existing gas distribution network infrastructure that can be repurposed and importantly any that cannot, thus reducing the overall cost of conversion.

The 'Executing the H21 Roadmap' document[9] clearly identifies the requirement to provide quantifiable safety-based evidence as the critical first step. This is the primary requirement, as without the safety-based evidence in place it is not possible to move towards a live community trial. Confirming that hydrogen represents a comparable and manageable risk to that presented by natural gas, in both the gas network itself and downstream of the ECV, is a critical forerunner to progression to a live community trial. This is supported in Ofgem's Future Insights series which states **"Due to the inherent similarities between hydrogen and natural gas, heating with hydrogen would perhaps require less change for consumers versus a switch to heat pumps or district heating[10]."**

BEIS are undertaking a £25m funding programme which will focus on provision of evidence 'Downstream of the ECV', predominantly within buildings, and technical development of appliances, known as the Hy4Heat project. The H21 NIC project complements the Hy4Heat programme to collectively provide the safety-based evidence required to progress towards a live community trial and subsequent policy decision. The

[7] Committee on Climate Change - 2019 Progress Report to Parliament - July 2019
[8] National Infrastructure Commission - National Infrastructure Assessment - July 2018
[9] Executing the H21 Roadmap
[10] Ofgem's Future Insights Series - The Decarbonisation of Heat

provision of the quantifiable safety-based evidence within the gas network should be undertaken by the regulated GDNs who have the expertise, access to assets and, importantly, access to significant innovation funding via the NIC to undertake their complementary programme of work in a timely way.

The gas industry has many decades of experience of distributing natural gas into people's homes and has developed an excellent safety record. Like natural gas, hydrogen is a flammable gas which produces heat as it burns. However, hydrogen has a number of properties that are different to natural gas which mean its propensity to leak, the effect it can have on materials, the rate at which it disperses and the conditions generated when it is ignited need to be further researched. These different properties give rise to the need for evidence as to how the gas network when converted to hydrogen can be operated as safely as the gas network is with natural gas today. H21 NIC Phase 1a and 1b was set up to study the likely gas tightness of the assets when operating with hydrogen and the consequences of failure in the event of a gas leak. H21 NIC Phase 2 of the H21 programme will fill vital gaps in the knowledge needed to operate a network safely in terms of emergency response, operation, maintenance and repairs, and will seek to demonstrate this on an unoccupied network. This research must commence in 2020 in order to underpin the development of a gas safety case for hydrogen and is important to support any decision by BEIS for community trials in early 2022.

This H21 NIC Phase 2 project aims to:

- Confirm how we can manage the network safely through an appraisal of network components, procedures, network modelling and testing.
- Validate network operations on an existing unoccupied network and provide a platform to publicise and demonstrate a hydrogen network in action through remote location testing.
- Develop an overall view of the risk of 100% hydrogen conversion by linking the H21 QRA with the Hy4Heat 'downstream of the ECV' QRA.

Establish how to frame and communicate complex information about a 100% hydrogen conversion in a way that best enables customers to understand and use it, and that avoids causing unwarranted confusion or negativity. Further details on the Phase 2 project technical description can be found in Appendix D.

The H21 NIC Phase 2 project compliments and actively collaborates with the many other projects currently being delivered which are looking at important aspects of use of hydrogen for heating. A view on how these projects fit together is summarised below.

Programme	Appliances	Gas detection	Network Integrity	Operational Procedures	Customer acceptance
Blend					
HyDeploy	Re-use existing appliances	Work using existing detectors plus new CO sensor	Materials and leakage assessment for 1-year trial	Controlled site some local procedures changed	First demonstration of use 2018
HyDeploy2	Re-use existing appliances	Develop approved new combined detectors	Network integrity assessment longer term	New procedures adopted on un-controlled site	First public demonstration of hydrogen use 2020
100% hydrogen					
H21	n/a	Not in scope	Major programme to assess asset	Major programme to assess	Element of social science research

			integrity and public safety	network control on existing network	
H100	New appliances needed	Market appraisal and selection for trial	n/a	New PE related procedures adopted on new network	Engagement with host site
Hy4Heat	New appliances being developed	Downstream of ECV standards to be developed	n/a	New standards downstream of ECV to be developed	Engagement regarding home conversion

Table 1: Hydrogen projects summary

2.1.3 The Development or Demonstration being undertaken

The overall Phase 2 project is broken down into four separate phases. The Project will undertake a scientifically robust experimental testing programme with two key phases, 2a and 2b, which will provide the following necessary evidence to assist with progression towards a live community trial:

- **Phase 2a – Appraisal of Network Operations:** Review, test and make recommendations to amend the operational and maintenance procedures required to operate a network on 100% hydrogen, below 7bar, including network components and initial operational requirements for conversion to 100% hydrogen.
- **Phase 2b – Unoccupied Network Trials:** Undertake an unoccupied network operations trial on an existing, undisturbed section of network, to demonstrate operational and maintenance procedures in action for a 100% hydrogen network and trial the conversion process.

The Project also includes continued work on key areas following the conclusions of the work in H21 NIC Phase 1 including:

- **Phase 2c – Combined QRA:** Combining the Phase 1 H21 QRA with the Hy4Heat QRA for an end-to-end quantification of the comparative risk between a 100% hydrogen network and the natural gas network.
- **Phase 2d – Social Sciences:** Extending the learning from H21 NIC Phase 1 customer perception research, along with work by Newcastle University for HyDeploy, to develop a suite of resources that NGN can use to communicate effectively with the public about a 100% hydrogen conversion. This will enable them to make an informed choice about the energy that best meets their needs, rather than one based on any misinformation or misunderstanding. Customer care and their inclusion in this journey is paramount to the success of the overall conversion project.

Overall the H21 NIC Phase 2 project aims to provide the evidence to demonstrate what is required to maintain and manage a GB 100% hydrogen network and what further investment may be needed to address any unsuitable operations or procedures. It will also continue to build on the foundational work of Phase 1 in the continued assessment of relative risk and building the safety-based evidence needed for customer engagement.

2.1.4 The Solution(s) which will be enabled by solving the Problem.

The H21 NIC Phase 2 project will provide further compelling safety-based evidence required to allow a 100% hydrogen conversion of the GB gas distribution network. Phase 1a addressed the first stages of scientific research into the 'leakiness' of different assets on the network when transporting hydrogen – a key factor in establishing the feasibility of conversion. Phase 1b undertook research and testing to answer the question of the relative risk of transporting hydrogen when compared with natural gas in the network and determined the main factors effecting this risk – again another key factor in establishing the feasibility of conversion. Phase 2 now needs investment to answer the questions as to how such a network can be managed safely including detailed appraisal of network components and procedures – this will further inform the likely feasibility of the use of hydrogen and address gaps in knowledge.

The information generated by the Project will determine the feasibility of using the GB gas distribution network to convey decarbonised gas in support of Net Zero and in doing so extends the life of the significant and ongoing investment in GB gas infrastructure for the long term. By re-using the gas distribution network to transport hydrogen, it would enable a wider UK roll out of whole energy systems strategies. For example, it would enable system coupling between electricity and gas through power to gas technology, would support accelerated decarbonisation of heavy transport, piping hydrogen direct to the forecourt and would reduce impact on end use customers.

The rationale for any natural gas to 100% hydrogen conversion programme must be a net reduction in emissions of carbon dioxide and other greenhouse gases, expressed as their carbon dioxide equivalent in line with the Kyoto Protocol and a specific focus on how to support the governments ambition for Net Zero by 2050. The carbon savings associated with an incremental conversion of the GB gas distribution network to 100% hydrogen are well defined and quantified utilising established technology. The table below summarises the results on a cumulative basis as required for Appendix B.

	To 2030	To 2040	To 2050
$MtCO_2$ eq saved	1.0	55.25	241.8

Table 1: Incremental carbon savings

As with the financial benefits it is important to note that these figures are based on a 30% conversion scenario as presented in Section 9 of the H21 NoE report[11], which was developed and published prior to the government move to a Net Zero target. The impact of a Net Zero impact will require further analysis to fully comprehend the level of hydrogen penetration required to deliver the enhanced reduction in carbon necessary.

2.2 Technical description of Project

The conversion of existing gas infrastructure across the UK is an extremely ambitious vision but is reflective of the challenge brought about specifically by a Net Zero carbon target. The impact of 100% hydrogen on end use appliances and in the home is being comprehensively investigated by the BEIS Hy4Heat £25m 'Downstream of the ECV' project. This Project needs to provide similar confidence on the feasibility of the gas network conversion in similar timescales.

The H21 NIC Phase 2 project will deliver an optimally designed scientific research, experimentation and testing programme, supported by HSE-SD and DNV GL, to demonstrate what will be needed to manage and maintain a 100% hydrogen network safely.

The key aim of H21 NIC Phase 2 is to further develop the evidence base supporting conversion of the gas network to 100% hydrogen in a timely way.

The key objectives of H21 NIC Phase 2 shall be to:

- Confirm how the gas network can be safely managed through an appraisal of network components, procedures, network modelling and testing.
- Validate network operations on an existing network and provide a platform to promote and demonstrate a hydrogen network in action through unoccupied network testing.
- Develop an overall view of risk of 100% hydrogen conversion/operation through updating of the existing QRA by linking the H21 QRA with the BEIS Hy4Heat 'Downstream of the ECV' QRA.

[11] H21 North of England Report - 2018

- Establish how to frame and communicate complex information about a 100% hydrogen conversion in a way that best enables customers to understand and use it, and that avoids causing unwarranted confusion or negativity.
- The H21 NIC Phase 2 project will provide confidence in the network operations to enable the move towards live community trials, keeping pace with the Hy4Heat project.

The H21 project teams have been and will continue to liaise closely with other innovation projects including Hy4Heat and SGN's H100, looking at 100% hydrogen conversion to ensure knowledge gaps in the holistic process are identified and that there is no unnecessary duplication of work.

This programme will be split into four primary phases which are described in more detail below:

- Phase 2a – Appraisal of Network Operations
- Phase 2b – Unoccupied Network Trials
- Phase 2c – Combined QRA
- Phase 2d – Social Sciences

2.3 Description of design of trials

This section provides an overview of the trial being undertaken. A full technical description of the Project can be found in Appendix D: Project Technical Description.

2.3.1 Pre-works – H21 Phase 1 NIC & H21 Field Trials NIA

H21 Phase 1 NIC Project

The H21 NIC Phase 1 project aimed to provide the first two pieces of the quantified critical safety-based evidence aimed at demonstrating how a 100% hydrogen GB gas distribution network can be managed to represent a comparable risk to that of the natural gas network. The scope of Phase 1 was aimed at demonstrating:;

- The background leakage position of the network, i.e. is it likely to leak more on 100% hydrogen and if so by how much and where? (Phase 1a)
- The consequences of hydrogen leakage both background and through network failures such as third-party damage and how this effects the societal risk associated with the network, i.e. how does the risk of transporting hydrogen compare with the risk of transporting natural gas? (Phase 1b)

Phase 1a testing is now underway with the test facility constructed at HSE-SD site in Buxton. This phase will determine if there are any assets that appear to be more susceptible to hydrogen leakage which will need to be considered for replacement as part of the conversion programme. Data from this testing will also give an indication of the overall 'leakiness' of the network when compared with natural gas. Phase 1b included converting the existing natural gas QRA to hydrogen for the network as well as several large-scale test programmes at Spadeadam to provide data against which the model could be validated. The testing programme for Phase 1b is advanced and the model that has been developed will provide a foundation on which to assess the main risk contributors when running a 100% hydrogen network and will allow an informed debate on how these can be managed. Phase 1 also investigated the public perceptions of the safety of hydrogen, how people respond to the possibility of using 100% hydrogen for heating and cooking and the public perception of the safety of hydrogen across the range of socio-demographic and geographic variables.

A third key element to the overall feasibility of conversion is an understanding as to how a 100% hydrogen network can be managed safely. This information will be needed alongside the information on 'leakiness' and relative risk to make an overall judgement on the feasibility of conversion. This is the rationale behind seeking the Phase 2 funding.

H21 NIA Field Trials project

In advance of seeking investment for Phase 2, NGN has funded a project to address some of the background information needed for Phase 2 including:

- Collating and sifting all network procedures and components for those where the conversion to hydrogen may influence the Basis of Safety (BoS), this work builds on the work started on the SGN H100 project. This piece of work will be completed by December 2019 and will result in a shortlist of procedures and components where a new evidence base will be needed to justify their continued use.
- Outline design for a gas micro-grid to be built at Spadeadam to be used to test and demonstrate procedures. The project has completed the conceptual design for the test area at Spadeadam and has progressed to full detailed design.
- Review of possible sites for undertaking an unoccupied network trial. The search area was originally confined to the NGN region but due to the lack of availability of suitable sites, a nationwide search is now underway.

2.3.2 Phase 2a – Appraisal of Network Operations:

Existing standards for the utilisation of natural gas have evolved over many years and have benefited from evidence of incidents and near misses over that time period. This experience is incorporated in standards for component design and operational procedures. When considering hydrogen, it is acknowledged that the benefit of this experience is lacking, so more detailed scientific knowledge and demonstration is needed to underpin any new operational procedures.

The methodology for technically appraising network procedures follows several steps, each designed to refine or evaluate the procedures or components used within the distribution network. The purpose of the exercise is to be able to understand what the current basis of safety is for a procedure or component, how it will change with 100% hydrogen and what evidence there is to support this. The evidence is crucial for two reasons; it will map out how safety can be managed in a network conversion and it will enable the unoccupied network trial to take place. The unoccupied network trial will serve as a demonstration of the procedures as well as contribute towards customer acceptance. The refining steps within the methodology are necessary as there is a large volume of procedures and components which manage the operation and maintenance of the gas distribution network, for example, stopple operations, squeeze offs, new connections etc. As part of the NGN funded H21 NIA Field Trials project the list will be triaged to generate a shortlist of key procedures and components which will go on to be evaluated in more depth in Phase 2.

Developing the safety-based evidence is the cornerstone of the Project and is where multiple sources of information will be collated to underpin the safe operation of the distribution network for the conversion to 100% hydrogen. This work will be led by HSE-SD and will build on the methodology applied in HyDeploy to demonstrate the suitability of procedures for a blended gas network.

It will be achieved by combining information from literature, modelling, experimental work and demonstration into a single narrative on the BoS for use with 100% hydrogen. Testing and demonstration work will be undertaken on the DNV GL micro-grid and the Master Test Programme (MTP) at Spadeadam will be targeted at areas where a new BoS needs to be demonstrated and is difficult to evidence through literature, laboratory-scale testing, modelling or theory.

Once built, the micro-grid test facility at Spadeadam will carry out tests as defined in the MTP to validate the network operation procedures and demonstrate the networks capability and suitability for 100% hydrogen conversion. The data from these trials will also continue to provide safety-based evidence that can be fed into the QRA to provide an updated picture of societal risk and network suitability.

The benefit of building a facility at Spadeadam is that it can also be used to train operatives for the Phase 2b – Unoccupied Network Trials. The controlled nature of the site is suitable for training operatives and can therefore also be used in the future as a training facility when required by the GDNs and National Grid.

There are several key objectives for Phase 2a which are defined below;

- **Phase 2a (i) Review of procedures:** To assess GDN procedures and identify those that should be suitable for a 100% network and those where further work will be required.
- **Phase 2a (ii) Build a micro-grid for demonstration and testing of procedures**: To build a gas demonstration network to accommodate full-scale network parameters and typical network components and run with 100% hydrogen or 100% natural gas.
- **Phase 2a (iii) Demonstrate procedures on purpose-built gas micro-grid**: To demonstrate procedures identified in (i) on the purpose-built gas demonstration network.
- **Phase 2a (iv) Establish hydrogen network modelling capabilities**: To test available hydrogen network models for validation against pressures and flows on the gas demonstration network and identify any further work required on these.
- **Phase 2a (v) Update QRA**: To review and update the QRA if required, with new information as it becomes available including results from Phase 2a.

2.3.3 Phase 2b – Unoccupied Network Trials

Nationally, operational hydrogen experience is limited to industrial applications; there is no experience on gas distribution networks supplying hydrogen to homes at present. For a live community trial to progress it is essential that this gap is addressed and a programme of testing developed and agreed by all project partners. The programme will also look to address any remaining engineering risks that may occur at the time of live community trials and subsequent conversion.

Conducting the unoccupied network trials would provide further confidence in moving to the community trials for both the Duty Holders and HSE who are ultimately responsible for the sign-off of the Safety Case.

In order to progress with confidence onto a live community trial, a trial of conversion and operation of an existing, in-situ, undisturbed gas network under controlled conditions (unoccupied) is imperative. H21 NIC Phase 1 testing will highlight any particular assets that could cause a problem for the conversion to 100% hydrogen Of the numerous hydrogen projects currently being undertaken in the UK, none are undertaking actual physical demonstrations of 100% hydrogen operations on a fully comparable existing live network asset. This is key to developing the evidence to move forward.

The NGN funded H21 NIA Field Trials project is determining the selection criteria and location for the unoccupied network trials site. The site will ideally be representative of a typical small-scale network post 2032 when the IMRRP programme will be complete. The site will likely contain both PE and metallic assets and ideally have existing pressure reduction equipment.

A series of network procedures and operations will be demonstrated on this unoccupied network with the aim of providing further confidence that safe operation of the network can be managed. Prior to conducting the unoccupied trial, a suitable safety management system for the trial area with a set of bespoke trial procedures will be developed with information drawn from the technical information gathered in Phase 2a.

The unoccupied network trial and demonstration of procedures will provide the confidence and final piece of evidence to industry and stakeholders that the repurposing of the GB gas distribution networks to 100% hydrogen is safe, efficient and manageable.

It is recognised that close collaboration between this project and the BEIS Hy4Heat project will potentially allow for the site to be utilised for downstream of the ECV demonstrations, again in an environment where customers will not be impacted. This will enable the decarbonisation of the gas distribution network to move onto the next phase of live community trials with end consumers with the required evidence, confidence and public acceptance required.

There are several key objectives for Phase 2b which are defined below;

- To demonstrate the findings from Phase 1 and Phase 2a on an existing unoccupied site demonstrating network operations in terms of conversion, new connections, network leakage, detection and repair on a more representative network

- Validate model network flows and pressures on a larger scale network
- Provide a platform to promote and demonstrate a hydrogen network in action
- To review any effect on the hydrogen from contaminants and stagnant odorization present in a mature natural gas asset of scale
- Greater understanding on the behaviours of hydrogen and other utilities will be better understood. Leakage migration results from testing at "Spadeadam" in Phase 1B would not be validated in the real-world environment for example when leaks occur in settled and undisturbed ground over decades.
- To gain greater confidence on the performance of assets installed to standards not representative of those practiced today.
- Minimise any potential delay in progressing to future community trials if the Network Duty holders insist on unoccupied live tests prior to roll out of Community Trials.
- Provide information on issues relating to dust and other mains debris movement in existing assets that would not otherwise be revealed in an idealised environment.
- Provide "real world" training for Network Operations staff prior to the Community Trials
- Operations on a network to prepare for the unexpected, as networks are complex by nature, while observing behaviours of field staff.

2.3.4 Phase 2c – Combined QRA

Following successful demonstrations on the simulation micro-grid and unoccupied network site, it is expected that a more robust basis of safety and network modelling will be available for the use of hydrogen in the existing distribution network up to the ECV. Hy4Heat have been and continue to investigate the basis of safety for operations 'after the ECV' and, in order to provide a full overview of risk for the conversion to hydrogen, it is proposed that H21 shall compare, analyse and align the two QRAs (Quantitative Risk Assessments) from the two innovation projects. This is an important time to carry out this operation to ensure compatibility of the adjoining systems (upstream/downstream of the ECV) to provide a full overview of risk prior to commencing community trials where the two innovation projects, Hy4Heat and H21 shall combine forces and demonstrate the conversion project on a live occupied section of the UK gas network.

Depending on the outcome of the combined risk assessment, additional safety mitigations and tests may be required for the live community trials.

There is one key objective for Phase 2c which is defined as:

- To link the H21 QRA with the Hy4Heat 'Downstream of the ECV' QRA to get an overall view on risk and what, if any, mitigations might be needed for the first trial area and overall on the network

2.3.5 Phase 2d – Social Sciences

Informed customers, equipped to make choices about their future energy supplies, are a critical outcome of the conversion process. Misunderstanding and misinformation could lead to poor customer choices or unwarranted concern. In a worst-case scenario, where widespread misunderstanding and misinformation lead to a wholesale rejection of conversion, the option of hydrogen could be lost entirely.

As a network operator we are the main point of contact with customers living within our networks. It is our responsibility, as the people undertaking the conversion, to ensure that customers are fully informed and equipped to make choices.

To do this, we need to establish how to frame and communicate complex information in a way that best enables customers to understand and use it, and that avoids causing unwarranted confusion or negativity.

A review of the social sciences elements of other hydrogen projects has been conducted, through the ENA smarter networks portal and through interfacing with the various projects. From this, it has determined that the Phase 2d social sciences scope is not being duplicated by another project.

Building on research completed during the H21 Phase 1 project, the HyDeploy project and Hy4Heat project, Phase 2d will explore the previous findings on the public's current awareness and perceptions of a potential hydrogen conversion and will provide a suite of resources that NGN can use to communicate effectively with the public about a 100% hydrogen conversion so that they may make an informed choice about their energy following a conversion. This will make it more likely that the public will choose the energy source that best meets their needs, rather than one based on any misperceptions or inappropriate concerns.

There are several key objectives for Phase 2d which are defined below;

- Produce a glossary of terms that explain the key concepts underpinning a hydrogen conversion and the safety testing that has been completed. NGN can use this glossary across all its communication materials, such as websites, leaflets, letters, and scripts for door-to-door engagement officers. The terms will be suitable for both business and domestic customers.
- Produce an animation that explains the reasons for a hydrogen conversion and what it involves. This will provide an engaging and easy to understand account of what will happen and why. It therefore forms a valuable resource for customers who have difficulties reading English. It could be readily translated into several languages.
- Develop a beach-to-meter display that will be used at community engagement events to aid explanations of how hydrogen is stored and transported, and the practicalities of how the conversion is achieved.

All these resources will be underpinned by three core principles: accessibility (they are easy to understand, including versions suitable for people who find it difficult to read English), no selling (the resources should enable informed choice rather than persuade people to use hydrogen); and candour (being open about what we know and don't know).

2.4 Changes since Initial Screening Process (ISP)

There are two changes to the original ISP:

Original ISP	Change
Phase 2c - Updating the QRA with the results from Phase 2a/b	Phase 2c Engage and combine QRA with Hy4Heat - This will provide a complete assessment of the risks to the public from a converted network supplying 100% hydrogen. Update H21 QRA model - Update H21 QRA model with new information as it becomes available including results from the Phase 2a/b as appropriate and other ongoing projects such as Hy4Heat. Risks for 100% hydrogen and mitigation - Once the QRA models have been updated, the combined QRA shall be applied to predict the risk impact of conversion to 100% hydrogen.
Phase 2d - Develop informative material for stakeholders to support engagement and future roll out of hydrogen for heat.	Phase 2d Public perception information gathering - Collaborative workshops bringing together new groups of the public with hydrogen professionals to co-create materials that explain the problems and answers. The output will be a glossary of terms that can be used in future communications, together with a set of infographics. Statistical modelling of feedback - Online survey that will produce a statistical model to identify the importance of price, safety,

	disruption and sustainability on reaction to a 100% hydrogen conversion. Development of customer targeted communication material - Use the results of the first phase of the Project to develop communication materials, such as website, leaflets, an animation and a beach-to-meter experience.

Section 3. Project business case

3.1 Overview

The benefits of converting the GB gas network to 100% hydrogen have not changed since the original submission of the H21 NIC Phase 1 bid. Converting the GB gas network would allow decarbonisation of heat for domestic, commercial and industrial customers with minimal impact, with only minor changes to heating and cooking technologies. Customer choice is maintained with no discernible changes required to customer behaviours. As with all energy transitions, there will be a cost to the customer at some stage. However, transitioning the GB gas network to 100% hydrogen could be one of the lowest cost solutions, given the reduced impact on both existing network infrastructure and customer premises compared to alternatives. If the transition was linked into the completion of the iron mains replacement programme, (early 2030s) costs to transition to hydrogen could be largely mitigated. Repurposing the GB gas network to hydrogen would maintain the high levels of resilience customers expect and rely upon and a system that by its nature can store large energy levels and deliver considerable flexibility when compared to other technologies.

The bulk availability of hydrogen within the GB gas network could facilitate the decarbonisation of transport through hydrogen fuelling stations and the development of electrical generation through decentralised and centralised technologies. Developing hydrogen for heat, therefore, could have far wider societal benefits, supporting the decarbonisation of other systems, the creation of new intellectual property and the creation of jobs and skills associated with the move away from natural gas systems to hydrogen. A 100% hydrogen gas distribution network could unlock the potential for system integration between the electricity and gas networks. This would drive capacity for more renewable technology, increased efficient energy balancing and a higher degree of resilience and flexibility.

A hydrogen gas distribution network can provide the fuel for any future district heating system. Hydrogen, as a central energy vector for the UK, is complementary to all decarbonisation technologies. A GB hydrogen gas network conversion would represent the biggest step forward in decarbonisation within the UK to date and would be a significant move towards meeting Net Zero.

3.2 Energy Demand

The UK, like most other countries, recognises the challenge of climate change. In the UK, this is a legal obligation to reach new zero carbon emissions by 2050, defined under the recently amended terms of the UK Climate Change Act 2008. Climate change is the most significant technical, economic, social and business challenge facing the world today. Prior to the H21 Leeds City Gate Project (H21 LCG), there had been little investigation into the opportunity to decarbonise the UK gas distribution network by utilising hydrogen at a scale commensurate with climate change targets.

The graph below, produced by Dr Grant Wilson at Sheffield University, in 'Figure 1: Size of decarbonisation challenge - UK' demonstrates the size of the decarbonisation challenge when considered in a net UK energy context:

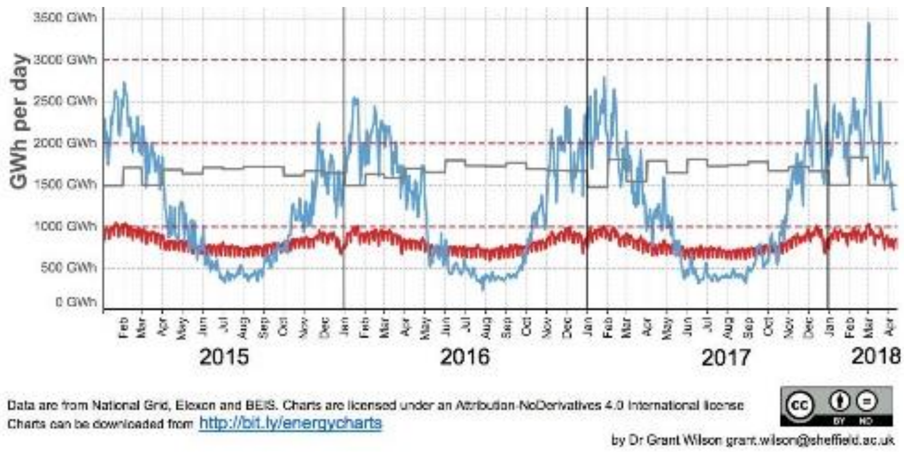

Figure 1: Size of decarbonisation challenge - UK[12]

In broad terms electricity demand equates to circa 20% of GB total energy use, with oil and gas generating around 40% of this. Currently around 50% of electricity generation is by decarbonised means, of which 20% is nuclear and 30% is renewables. Whilst some movement has been made to decarbonise both oil and gas it is nowhere near the scale seen in electricity. In general terms that means in total only around 10% of the total energy demand has been decarbonised.

Over the last 40 years the UK has made substantial investments in its natural gas infrastructure. These include gas production, national transmission, storage, interconnectors as well as import terminals using Liquified Natural Gas (LNG). The total gas required in 2017 was 875 TWh with imports contributing 36%[13]. The expectation is that as UK conventional production declines, import dependency will continue to increase. This gas infrastructure supports a market that includes supplies to power generation plants, industry, commerce and domestic households.

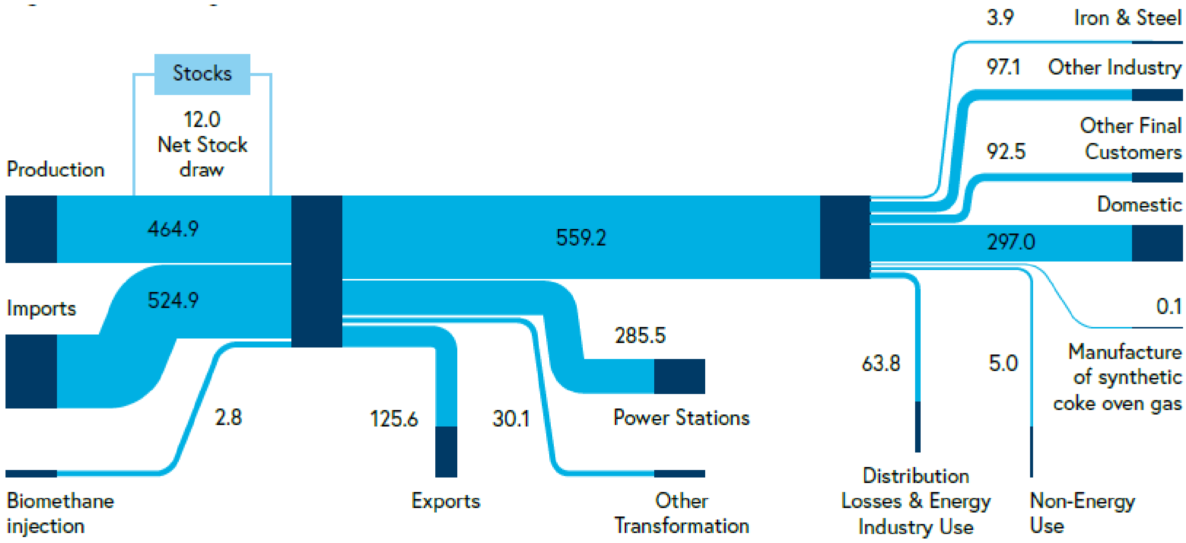

Figure 2: Natural Gas Flow Chart 2017 (TWh)[13]

The existing gas network is well proven in provision of energy through a highly secure network which has been developed to be extremely resilient in almost all weather conditions. The network has been designed to meet the energy demand for an extreme weather event which could statistically occur once every 20 years. This means an exceptionally cold event which occurs when all appliances are on. In the UK in 2018 the 'Beast from the East' met this characteristic, validating the gas network design.

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[12] Size of decarbonisation challenge - Graph - Dr Grant Wilson
[13] BEIS (2017) Digest of UK Energy Statistics 2018

Hydrogen conversion provides a long-term solution to climate change which utilises both the strength of the existing gas networks, linked to supporting the decarbonisation of GB electricity networks. This will provide future customers with the same level of choice and enhanced energy security compared to what is currently offered by gas and electricity availability today.

3.3 Network licensee benefits

3.3.1 Aligned with Strategic direction

Since publication of the H21 LCG report, there have been numerous publications supporting the potential of a 100% hydrogen gas network conversion. All express the need for urgent action to provide the elements of critical evidence that would allow strategic policy decisions to be made. The most notable were firstly the May 2019 publication by The Committee on Climate Change (CCC) 'Net Zero – The UK's contribution to stopping global warming[14]'. Secondly, the October 2017 publication by the UK Government, 'The Clean Growth Strategy'[15]. This latter publication credits a 100% hydrogen conversion as one of the most credible options for deep decarbonisation.

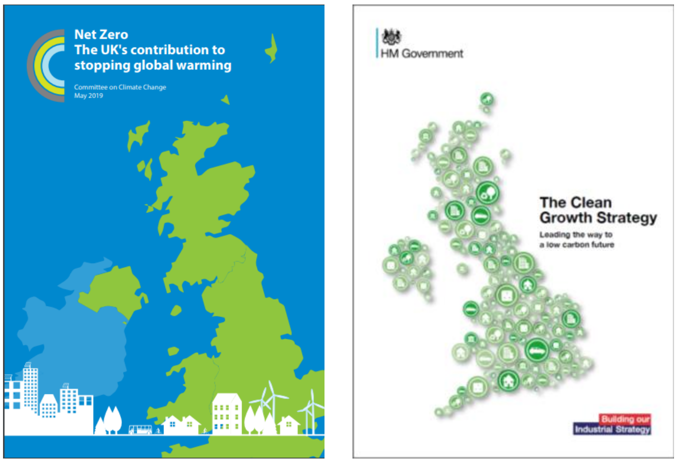

Figure 3: HM Government recent publications

- **Critical evidence:** The UK Government's Hy4Heat programme (£25m) and the UK gas industry's H21 NIC project (£10.3m), are now underway and due to complete in 2020/21. These programmes will provide much of the critical safety-based evidence for hydrogen conversion. A brief overview of each programme is provided below:
- **£25m 'Hy4Heat' Programme** led by the UK Government's Department of Business Energy and Industrial Strategy (BEIS). This project will provide the quantified safety-based evidence within domestic, commercial and industrial buildings. It will also provide capital stimulus to the appliance sector to produce a range of 100% hydrogen compatible appliances, burners and meters.
- **£10.3m 'H21 – NIC' Programme** led by Northern Gas Networks in conjunction with all the gas networks of Great Britain (Cadent, SGN, Wales and West Utilities) was awarded funding by Ofgem in November 2017. The H21 NIC project is designed to complement the BEIS programme and focuses on providing the safety-based evidence for 100% hydrogen conversion on the UK GDN's network of pipes supplying gas to customers.

The two programmes are shown diagrammatically in Figure 4: H21 NIC and Hy4Heat.

[14] Committee on Climate Change - Net Zero - May 2019
[15] HM Government - The Clean Growth Strategy - October 2017

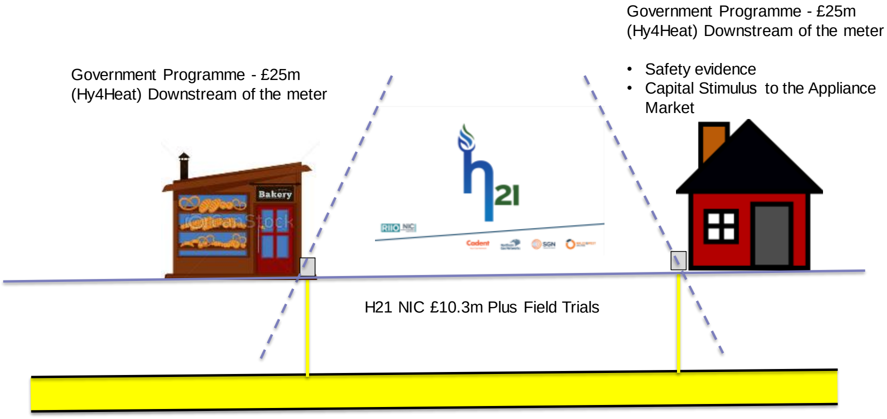

Figure 4: H21 NIC and Hy4Heat

The H21 concept is to convert the UK gas distribution network to 100% hydrogen. This can be achieved using existing technology and would maintain the benefits of gas and the gas networks in the energy mix for the long-term future. If undertaken, such a conversion would represent an enormous contribution, e.g. 83% of heating and 41% of power generation[16], to meeting climate change obligations.

100% hydrogen conversion does not negate the need for other decarbonisation initiatives, e.g. energy efficiency measures, renewables, nuclear, district heating, 'bio'-energy, etc. Rather a large scale transition to hydrogen for heat would be complementary to other technologies allowing more substantive decarbonisation when considering the whole energy system. Decarbonisation of GB gas network through hydrogen will take time, as would any approach, but with 30 years remaining to deliver Net Zero work needs to continue to maintain momentum, deliver the answers needed and, where appropriate, support the government in preparing the policy landscape required to decarbonise our energy systems. Hydrogen conversion represents a timely, credible and deliverable strategy.

The H21 project gives the UK a unique opportunity to lead the world in large-scale decarbonisation strategies. With continued local, national and international support, the evidence can be gathered to make this a reality.

3.3.2 Individual network benefits

The short-term benefit to the GB GDNs of this project would be the quantification of risk of converting GB gas network to 100% hydrogen, enabling them to:

- Create an inventory of procedures that are fit for purpose for use with hydrogen, whilst identifying procedures that will require future investigation with areas of research required to enable progress to unoccupied trials and then onto live community trials.
- Develop knowledge of how hydrogen networks can be converted and managed from the network operations testing.
- Identify aspects of the tools commonly used that are no longer fit for purpose and engage supply chain in dialogue.

3.3.3 New opportunities

The transition to the use of hydrogen provides a platform for wider developments of the gas network in the transition to a low carbon economy. Recent policy changes mean that conventional liquid-fuelled transport is being phased out over the next 25 years[17]. Hydrogen offers alternative vectors alongside electrification, with an increasing recognition that constraints to electricity transmission and distribution capacity, as well

[16] Committee on Climate Change, Net Zero – Technical report May 2019
[17] Reducing emissions from road transport: Road to Zero Strategy', HM Government, July 2018

as charging times and battery capacity, mean that both gas and electricity vectors are likely to operate in tandem, with hydrogen fuel cell technology increasingly seen as the primary solution for heavier fleet. This provides an opportunity for the provision of hydrogen to gas transporters for the installation of a hydrogen network for the transport sector. Other GDNs are currently investigating the use of hydrogen for this market, addressing the implications and opportunities for the gas distribution network.

Enabling the adoption of hydrogen brings forward opportunities for flexible power generation to balance intermittency, as well as considerations as to how the electricity and gas networks integrate to the benefit of customers and to decarbonise transport. NGN's InTEGReL (Integrated Transport, Electricity and Gas Research Laboratory) facility with partners Northern Power Grid, Newcastle University, Northumbrian Water and Siemens addresses these opportunities in terms of integration of gas, electricity and transport. The linking of electricity and gas infrastructure via technologies such as electrolysis could deliver advanced flexibility, new markets and services simply not considered in our current landscape.

Hydrogen for transport is particularly significant in the heavy haulage sector such as HGV and trains. Following recent announcements in the media[18], it is the intention that hydrogen trains will be running on the rail network by 2022, with the goal of replacing all diesel stock by 2040.

3.3.4 Underpinning the life of the network

The use of hydrogen capitalises on the existing asset base and extends the life of the GB gas network. This exploits the sunk costs associated with an existing asset and avoids its costly decommissioning.

3.4 Customer benefits

83% of households obtain their energy for heat from the gas network, typically for use in modern, efficient gas boilers. Heating infrastructure is based around circulating hot water systems. A low carbon solution for heat which utilises existing infrastructure offers a minimum impact solution for customers, alongside lower levels of knowledge and usage change.

3.4.1 Financial benefits

If the gas network can be used to transport a zero-carbon gas (hydrogen), then customers can continue to use energy in a similar manner as they do today, without major changes to their homes. If this is not going to be possible, then an equivalent quantity of low carbon energy for heat must be delivered via another means, invariably meaning significant upheaval to the internal components of the home, a change in behaviours and potentially higher capital costs.

The financial benefits to gas customers have been calculated in detail using the information provided in the H21 NoE report[19] and further interpreted using the KPMG 2050 Energy Scenarios report[20]. This has used the incremental conversion scenario presented in Section 9 of the H21 NoE report, which assumed the conversion of circa 30% of UK gas customers by 2050.

The KPMG 2050 Energy Scenarios report suggested significant differences in cost and deliverability between an all-electric and alternative gas options for decarbonisation. The all-electric option for decarbonisation was estimated to have a cost differential per consumer of 2.74 (midpoint – see Appendix B: Benefits Justification) times that of a gas alternative. Additionally, practical obstacles between all-electric and gas options were respectively considered high as opposed to low/medium.

The savings shown in the table below are calculated based on this 2.74 factor between an all-electric option and a 100% hydrogen conversion option. These are expressed

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[18] Hydrogen fuel cell trains to run on British railways from 2022', The Telegraph, January 2019

[19] H21 North of England Report - 2018

[20] 2050 Energy Scenarios, KPMG, July 2016

cumulatively on a Net Present Value (NPV) basis (discount of 3.5% for first 30 years and 3.0% thereafter), consistent with Appendix A: Benefits Table.

	2020	2030	2040	2050
Cumulative NPV (£m)	£0	£5,033	£30,506	£46,191

It is important to note that these figures are based on a 30% conversion scenario as presented in Section 11 of the H21 NoE report. This equates to a GB average annual saving between 2030 and 2050 of around £2.3bn per annum.

No costs associated with additional direct benefits which would arise from an incremental gas network conversion to 100% hydrogen have been included. These would include minimisation in transportation changes for customers as hydrogen fuelling stations would be built to support decarbonisation of transport.

3.4.2 Non-financial benefits

There are significant tangible non-financial benefits to an incremental conversion of the UK gas distribution network to 100% hydrogen. Firstly, the perceived benefit to customers whereby **customers of tomorrow have the same choice as customers of today**: gas or electric. It is recognised that to meet climate change obligations, the UK cannot continue to burn unabated natural gas for decentralised heat, which means some change for customers is inevitable. Secondly, enhanced energy delivery and utilisation technology options provided by a hydrogen and electric energy landscape (see Section 3.2.3 above) would provide customers with enhanced opportunities and choice in the home, as well as providing the Government with more options for energy efficient and low carbon solutions, vital when considering the wide range and age of buildings in the UK, the construction of which largely dictates the heating technology utilised.

Additional benefits arise when considering a social impact perspective, with improved air quality resulting from hydrogen vehicles and the much more rapid decarbonisation of heavy transport specifically.

3.5 Environmental benefits

The rationale for any natural gas to 100% hydrogen conversion programme must be a net reduction in emissions of carbon dioxide and other greenhouse gases, expressed as their carbon dioxide equivalent in line with the Kyoto Protocol. The carbon savings associated with an incremental conversion of the GB gas distribution network to 100% hydrogen are well defined and quantified utilising established technology. The table below summarises the results on a cumulative basis as required for Appendix A.

	To 2030	To 2040	To 2050
$MtCO_2$ eq saved	1.0	55.3	241.8

As with the financial benefits, it is important to note that these figures are based on a 30% conversion scenario as presented in Section 9 of the H21 NoE report. The actual rate of conversion is dictated by the speed at which hydrogen production can be established.

Air pollution is the biggest environmental threat to health of the UK with between 28,000 and 36,000 deaths per year. Along with these deaths, there are the associated costs to the National Health Service. In May 2018 Public Health England[21] estimated that the health and social care costs of air pollution in England could reach £5.3 billion by 2035, unless action is taken. In 2017, the costs were £42.88 million for diseases where there is a strong association with air pollution: coronary heart disease, stroke, lung cancer, and child asthma.

[21] Public Health England - Estimation of costs to the NHS and social care due to the health impacts of air pollution - May 2018

Section 4. Benefits, timeliness, and partners

4.1 Accelerates the development of a low carbon energy sector and/or delivers environmental benefits whilst having the potential to deliver net financial benefits to future and/or existing Customers (Criteria a)

4.1.1 (i) How the Project could make a contribution to the Government's current strategy for reducing greenhouse gas emissions, as set out in the document entitled "the Carbon Plan" published by DECC (now known as BEIS), or its successor, in particular:

- *What aspects of the Carbon Plan (or its successor) the Solution facilitates;*

The Committee on Climate Change (CCC) recent report "Net Zero – The UK's contribution to stopping global warming" May 2019[22], recommended that the UK adopt a new carbon target of Net Zero. This was well received within government and in June 2019 the UK announced it would move its carbon targets towards this far more challenging position. The CCC report also recommended there be a substantive move towards scale demonstrations of low carbon heat solutions, including hydrogen.

Whilst great strides have been made, both within the existing H21 programme and through SGNs H100, in the work to develop a body of evidence supporting the case for hydrogen, there is still research required to provide the evidence and level of confidence needed by government. Therefore to support this clear ambition, it is necessary to advance the research and evidence gathering undertaken through the H21 NIC project to broaden and extend the knowledge to satisfy that need to such an extent that allows government to support steps towards at scale trials to take place as referred to by the CCC report.

- *The contribution the roll-out of the Method across GB can play in facilitating these aspects of the Carbon Plan (or its successor); and*

Currently there are no proven at scale solutions to decarbonise heat, that is to say nothing has been proven in terms of safety, customer acceptance, reliability or cost whether that be low carbon heat via electricity or a gas-based solution.

The work undertaken in the H21 NIC Phase 1 project and Phase 2, if this bid is successful, aims to establish credible evidence to support and drive the use of hydrogen for heat. An aim of the H21 programme is to identify the impact of hydrogen on existing gas infrastructure and establish which components can support the transition, thereby minimising both the cost of transition and disruption to the customer.

To achieve this in the most efficient way for customers, the Project will continue to consult and share learning with other related programmes such as H100 and Hy4Heat.

The work being undertaken in the UK Governments Hy4Heat programme will see the development of hydrogen cookers, fires and boilers with the longer term aim that appliance manufacturers will develop hydrogen ready appliances, with the ability to operate using either natural gas or hydrogen to facilitate and reduce the cost of conversion.

Part of the H21 vision is to prove hydrogen is a safe and viable replacement for natural gas, using the existing infrastructure. This will, in combination with the Hy4Heat programme, bring together a methodology of change that offers low disruption combined with high reliability, providing low carbon heat to consumers. The design of the GB gas network is highly flexible, therefore the roll-out programme can be developed and funded at a pace corresponding with the UK Government's appetite for change and delivery of Net Zero by 2050.

- *How the roll-out of the proposed Method across GB will deliver the Solution more quickly than the current most efficient method in use in GB.*

The Project aims to contribute towards the conversion of the GB gas network to 100% hydrogen. There is currently not a method in use in GB to undertake this. By working closely with the wider industry, sharing knowledge, learning and being agile in approach

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[22] Committee on Climate Change, Net Zero – Technical report May 2019

will help deliver a more precise pathway to hydrogen than working in isolation and so, whilst hydrogen is not currently deployed across GB, it is felt this collegiate approach will help GB be more efficient in approach, to deliver a more rapid progression than would otherwise be likely.

4.1.2 (ii) If applicable to the Project, the network capacity released by each separate Method

This project does not release any network capacity, rather given the lower calorific value of hydrogen relative to natural gas, the system capacity utilisation will increase across the demand bands.

4.1.3 (iii) The proposed environmental benefits the Project can deliver to customers

The rationale for any natural gas to 100% hydrogen conversion programme must be a net reduction in emissions of carbon dioxide and other greenhouse gases, expressed as their carbon dioxide equivalent in line with the Kyoto Protocol. The carbon savings associated with an incremental conversion of the GB gas distribution grid to 100% hydrogen are well defined and quantified utilising established technology. The table below summarises the results on a cumulative basis as required for Appendix A.

	To 2030	To 2040	To 2050
$MtCO_2$ eq saved	1.0	55.3	241.8

These figures, and the financial benefits, are based on a 30% conversion scenario as presented in section 9 of the H21 North of England (NoE) report[23], which was developed and published prior to the government move to a Net Zero target. The actual rate of conversion is dictated by the speed at which hydrogen production and distribution can be established.

Air pollution is the biggest environmental threat to health in the UK, with between 28,000 and 36,000 deaths a year attributed to long-term exposure. There is strong evidence that air pollution causes the development of coronary heart disease, stroke, respiratory disease and lung cancer, and exacerbates asthma.[24]

The major outdoor pollution sources include vehicles, power generation, building heating systems, agriculture/waste incineration and industry.

Air quality is closely linked to earth's climate and ecosystems. Many of the causes of air pollution are also sources of high CO_2 emissions, i.e. combustion of fossil fuels.

4.1.4 (iv). The expected financial benefit the Project could deliver to customers

In developing the narrative around this specific question, the cost estimate is based solely on current knowledge and available technology. This creates a degree of uncertainty regarding anything but near future projects. Given the known cost reductions that transpire from improved economy of scale, and new or enhanced technology, the financial benefits outlined are conservative. To fulfil the governments target to deliver Net Zero, there is not a 'Do-Nothing' option. As such, whichever outcomes transpire, the change to a low carbon economy is likely to result in increased costs, at the very least in the short term. The challenge is to identify which of the options are considered to deliver the best value for customers. The ambition of the H21 programme is to repurpose existing gas infrastructure for the use of hydrogen and to minimise any disruption to the customer. While some reinforcement of the network will be required to convert the supply to meet 1:20 peak demand, surplus capacity off-peak could be used to drive the transition of transport and power generation to hydrogen.

Work was undertaken within the H21 NoE NIA project, a collaborative piece of work between Northern Gas Networks, Cadent Gas and Equinor, which estimated the costs to deliver a hydrogen transition across the Northern Powerhouse area. The following extract

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[23] H21 North of England Report - 2018

[24] Public Health England Report: Review of interventions to improve outdoor air quality and public health, March 2019

presents the findings from that work. Given the breadth of scope for the NoE area, it is not unreasonable to assume a similar position should a wider footprint be undertaken and additional savings are likely from that scale up of operation. It is worth noting that the H21 NoE report highlighted a significant cost benefit when compared to the original cost estimates determined within the H21 Leeds City Gate (LCG) blueprint.

"The H21 NoE project provides a CAPEX and OPEX saving of 25% and circa 50% respectively when compared on an energy basis against the original H21 LCG project costs."[25]

From the same report comes the following:

H21 NoE is a fully aligned major infrastructure development with a long asset lifetime and a potential monopoly position. Therefore, a finance model for the H21 NoE project has been established based on the principles of regulatory financing.

A finance model has been developed and benchmarked against NGNs fully detailed regulatory finance model to confirm it is directionally accurate. This finance model assumes all the new hydrogen infrastructure including the Hydrogen Production Facility, interseasonal hydrogen storage, hydrogen transportation system, carbon transport and storage and appliances are part of a new national 'hydrogen regulated asset'.

This is based on the factual and ethical assumption established in Section 9.0 with the key statement being: It is important not to think in terms of different types of gas having different costs. The individual customers' gas bills are not based on gas type, they are based on energy. As such, it is the mechanisms to distribute the cost that are important not the type of gas the customer is using.

The model uses Net Present Value (NPV) where the NPV is set to zero, depreciation is set to 45 years (appliances 10 years) and the WACC is seen as the internal rate of return of the project. The output from this model is used to calculate the new unit price and new annual gas bill for UK gas customers. For the hydrogen regulated asset the additional unit cost for UK gas customers is £3.8/MWh. Based on a standard gas bill with current consumption at 14,200 kWh per year this translates to an additional £53 pa and total overall gas bill increase in 2035 (peak) from £780 pa (using 2035 gas prices £23/MWh) to £837 pa, i.e. a circa 7% increase.

Other scenarios, presented in Section 11.0, have the potential to significantly reduce this impact further still.[26]

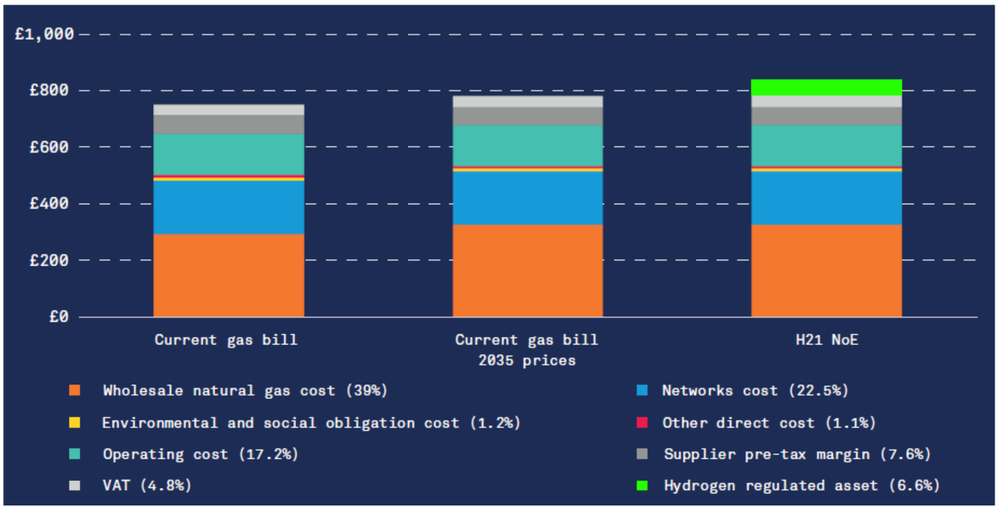

Figure 5: Impact of H21 on total annual gas bills (peak in 2035) – taken from figure ES.10: NoE Report

[25] H21 NoE Report, Executive Summary, Page 17
[26] H21 NoE Report, Executive Summary, Page 18

In terms of the capital investment for the gas conversion of the NoE against an all-electric future, the financial benefits are in the following table:

	To 2030	To 2040	To 2050
Hydrogen conversion	£3,265m	£21,200m	£49,026m
All-Electric (using 2.74 scaling factor)[27]	£8.937m	£58,020m	£134,175m
Costs avoided for customers versus All Electric	£5,671m	£36,220m	£85,150m
Savings to gas customers versus All Electric (NPV)	£5,033m	£30,506m	£46,191m

Table 2: Financial Benefits up to 2050

The existing GB gas network is well proven in provision of energy through a secure network which has been developed to be robust and secure in all weather conditions. The network has been designed to meet the energy demand for an extreme weather event which could statistically occur once every 20 years, meaning an exceptionally cold event triggering a surge in demand as appliances work hard to maintain comfortable levels of heat in the home. It is important to note that the warming nature of climate change does not automatically translate into lower peak demand. Moreover, as the climate becomes more unstable the likelihood of extreme weather events increases.

During February and March 2018, the 'Beast from the East' weather period met this characteristic peak position, validating the UK gas network design.

If the GB gas network can be repurposed to transport a low/zero carbon gas it will allow the UK to capitalise on this existing national asset.

4.2 Provides value for money to gas Customers (Criteria b)

4.2.1 (i) How the Project has a potential Direct Impact on the Network Licensee's network or on the operations of the GB System Operator

This Project has a direct impact on all GB gas distribution Licensees and is being collaboratively funded and executed. If the critical evidence to allow a 100% hydrogen conversion is established and a subsequent policy decision to convert the UK incrementally is taken, it will avoid stranding this asset and the extensive decommissioning costs. It will also ensure that customers of tomorrow have the same choice as customers of today - gas or electricity across the energy landscape (heat, electricity and transportation).

Importantly the transition of the UK gas infrastructure to 100% hydrogen is also highly supportive of the wider energy system. Considering our energy infrastructure from a whole energy systems perspective allows us to develop connections from the hydrogen gas network across to transport, to fuel trains and other large fleet. It supports at scale deployment of electrolysis, which can be a valuable interface to the electricity grid, providing demand side response and frequency services, allowing deeper penetration of green electricity on to the grid. New market propositions could also be established to provide peak flexibility services across both gas and electricity, broadening opportunity and delivering a market driven low carbon energy system. The simple act of piping hydrogen to refuelling centres for heavy transport would remove a significant number of fossil fuel tankers from UK roads, easing congestion, improving air quality and reducing carbon emissions from that sector.

4.2.2 (ii) Justification that the scale/cost of the Project is appropriate in relation to the learning that is expected to be captured

The cost of the Project is considered low compared to the benefits and learning which it unlocks. As shown in Appendix B – Benefits Justification, to invest £6,80m of NIC funding (with a further £761k of funding from the GB GDNs and National Grid) is a

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[27] KPMG '2050 Energy Scenarios Report', Executive Summary, page 7.

fundamental step in the realisation of 100% hydrogen conversion which has the potential to generate £85bn of savings for gas customers, this is a small investment working towards a large saving. This saving is based on a conservative customer conversion rate of 30% of the 8.8 million gas customers in the NoE. (see Appendix B: Benefits Justification). If all the UK gas customers were converted to 100% hydrogen this saving could be circa £280bn compared to the all-electric solutions.

The project scale has been carefully designed to maximise the learning and minimise the costs. The challenge for the H21 NIC project is to design a testing plan which can provide the compelling safety-based evidence without requiring significant funding for the research. The costs have been minimised by value engineering the project across the following principal areas. (See Appendix D: Detailed Project Description for more detail):

Repurposing testing facilities: Through the H21 NIC Phase 1 project, a unique testing asset has been developed at the DNV GL Spadeadam site. DNV GL funded the development of properties to support testing in conjunction with the H21 programme. The site currently connects to a small pipeline loop. This Project would expand the surrounding infrastructure further to create a micro-grid and enhance the site with additional test facilities. The re-use of the Spadeadam site reduces costs in two ways; firstly by re-using existing infrastructure installed in Phase 1b and secondly, by lowering costs associated with infrastructure testing.

Utilising the gas industry's historic expertise: Highly experienced project partners HSE-SD and DNV GL, along with the GB network operators, have been utilised to define and collectively agree the four proposed phases of work. This has drawn upon existing evidence and purposefully avoids unnecessary duplication of work previously undertaken. This has been developed by undertaking a gap analysis as presented in Appendix C: Gap Analysis.

Coordination with other hydrogen projects: Cooperation with other hydrogen projects, including Hy4Heat and SGN H100 to understand their programme of work and shared commonality of purpose, in order to identify opportunities for closer working relationships and more refined testing is a priority for the Project. An outcome of this cooperation is the accelerated learning across the UK hydrogen landscape to support the Government Net Zero ambition. In the past, these relationships have also provided access to established gas risk modelling systems to extrapolate results, and therefore avoiding extensive development costs. The Project team will coordinate with other hydrogen projects by attending GDN project coordination meetings, where they will deliver learning and drive engagement across the hydrogen community.

Developing the H21 NIA Field Trials project: This will save significant costs by reviewing the current GDN procedures to ensure the test facility can achieve the agreed master test plan. It will also improve the programme through the planned expansion to Spadeadam, advanced selection of the remote network included in Phase 2b – Unoccupied Network Trials and cataloguing/triaging all existing and relevant gas industry procedures.

Project partners selection: The Phase 1 project partners and industry experts have been maintained to ensure continuity of expert knowledge of the H21 programme. The project partners are also involved in other UK based hydrogen projects, which minimises duplication of work. All partners are agreed that this bid represents an optimised testing plan to solve the problem statement.

Ensuring credibility of results: The tests, and therefore test partners, must produce credible results that can be trusted by government, industry and wider stakeholders. As such this programme supports cross-examination of findings between the HSE and DNV GL teams to provide rigour and certainty.

4.2.3 (iii) The processes that have been employed to ensure that the Project is delivered at a competitive cost

The Project shall be developed through gap analysis based on H21 NIC Phase 1 project findings. The H21 NIA Field Trials design project shall undertake the design of the proposed installation for Phase 2a by developing a more flexible design to better serve the various undefined network operational activities that will be required on a below 7 bar hydrogen network.

By reutilising the existing infrastructure and test facilities that were constructed in Phase 1b, there will be a reduction in costs compared to delivering a full new test facility to meet project requirements.

The two primary partners, DNV GL and HSE-SD, have been selected based on their specific and unique ability to add value to the Project and their existing knowledge of the H21 programme. The two partners agreed to provide rates in line with inflation, based upon the Phase 1 costings and these are fixed for the duration of this NIC project. They are also both integrated into several other hydrogen projects for the GB gas networks and so provide added value to the project through shared learning and knowledge dissemination. They have unique credibility when disseminating test results due to their historical expertise and/or connections with the Health and Safety Executive. Rates for these two partners are in line with pre-tendered network frameworks rates or the agreed rates from the HyDeploy project and the H21 NIC Phase 1 project for DNV GL and the HSE-SD.

Other major costs, e.g. design, supply of equipment, construction of remote site, security etc., will be awarded based on a combination of competitive tenders or one of the gas distribution network’s existing framework agreements.

The GB GDNs have executed many projects through the IFI, NIA and NIC structures and have well-established contractual and governance arrangements for delivery. The project has an experienced management team structured to deliver the project cost-effectively, see Appendix E: Governance and Organogram for more details.

A detailed budget has been developed for the Project, as shown in Appendix H: Cost Breakdown, and is summarised in Table 3: Total Labour Across Project: (Figures exclude contingency).

	Total Labour Across Project						Equipment	IT	Total
	No. of staff	Man-days	Rates Range	Rates Average	Labour Costs	Contractor costs			
	FTEs	Days	£/day	£/day	£k	£k	£k	£k	£k
Phase 2A	15.0	3,186	350-1,612	793.16	842	1,685	1,808	15	4,350
Phase 2B	8.9	1,886	350-1,612	590.26	872	241	1,675	15	2,803
Phase 2C	1.4	295	900-1,592	1,046.11	32	277	0	0	308
Phase 2D	1.9	400	400 - 500	380.03	32	120	0	0	152
NIC Funding request					1,778	2,323	3,483	30	7,614
	Additional External Contribution Value (DNV GL at Spadeadam)								225

Table 3: Total Labour Across Project

4.2.4 (iv) What expected proportion of the potential benefits will accrue to the gas network as opposed to other parts of the energy supply chain, and what assumptions have been used to derive the proportion of expected benefits

Establishing evidence to support the transition of the UK gas networks to 100% hydrogen would, if implemented, extend the life of the UK gas industry, securing thousands of jobs long-term, creating new highly skilled hydrogen specialists, and would drive the UK economy to lead the low carbon transition globally. Importantly it would retain customer choice, by replicating the current options for heat and would therefore mitigate the need for a change to customer behaviour. The continued utilisation of the UK gas network would further support the wider energy transition, enabling hydrogen refuelling facilities fed from the UK gas infrastructure, as well as supporting the electricity sector with new hydrogen power generation, considered an important factor in maintaining power stability in the future.

The transition to hydrogen would also have a large impact on GB heavy industry, particularly those sectors with high heat needs, such as bakeries, the glass industry etc. and which are therefore extremely difficult to resolve unless via the hydrogen route.

4.2.5 (v). How Project Partners have been identified and selected including details of the process that has been followed and the rationale for selecting Project Participants and ideas for the Projects

The existing H21 NIC Phase 1 project team consist of, NGN SGN, Cadent and Wales & West Utilities, alongside our technical partners from HSE-SD and DNV GL.

In working through the Phase 1 project, discussions have been undertaken to develop concepts and ideas for the follow-on phase of work to create a body of evidence that has industry wide credibility, and which is also beneficial and supportive of government ongoing hydrogen research, Hy4Heat for example, and inform future thinking. In light of the current mobilisation and specifically the inherent learning, skill and knowledge that has been built up over the period working on the H21 NIC Phase 1 project, it was determined that this next phase of work would continue with existing partners, with the welcome addition of National Grid (NG), to minimise disruption and cost. The rationale for selection maintains pace, focus and staff mobilisation to maximise the value to customers from continued investment in hydrogen research.

4.2.6 (vi). The costs associated with protection from reliability or availability incentives and the proportion of these costs compared to the proposed benefits of the Project.

This project does not expect any impact on reliability or availability incentives.

4.3 Is innovative (i.e. not business as usual) and has an unproven business case where the innovation risk warrants a limited Development and/or Demonstration Project to demonstrate its effectiveness (Criteria d)

4.3.1 (i). Justification for why the Project is innovative and evidence it has not been tried before;

The aim of the H21 programme is to determine the suitability of GB gas distribution infrastructure for the conveyance of 100% hydrogen. Specifically, to focus on the existing assets which will be in use post conversion within the networks. This is a key discriminator when compared to other important work in this area such as the SGN H100 project which, in terms of a network trial is utilising new PE mains and new network components. It is important to identify the impact of hydrogen on a wide variety of existing metallic mains and assets across GB gas distribution infrastructure to repurpose as much as is practicable and safe to do so, thereby minimising future customer costs as a result of such a decarbonisation scheme.

The H21 team work closely with all GDN partners to explore the areas of research undertaken to minimise potential overlap and, importantly, to develop pathways which are interconnected and supportive, to enable a low cost but accelerated programme of research across the UK to deliver a future hydrogen gas network. Please see Appendix C – Gap Analysis for further information.

Equally, the team regularly engage globally through literature reviews to understand work undertaken by the wider hydrogen community, again to minimise spend and unnecessary work and to pool the UK research position as global leading experts in the hydrogen community.

4.3.2 (ii). Justification for why the Project can only be undertaken with the support of the NIC, including reference to the specific risks (e.g. commercial, technical, operational or regulatory) associated with the Project.

The H21 NIC project is complementary to the Hy4Heat programme which is downstream of the ECV with the H21 project focus being upstream.

The provision of the quantifiable safety-based evidence within the gas network should be undertaken by regulated GDN monopolies who have the expertise, access to the assets and, importantly, access to significant innovation funding via the NIC to undertake their complementary programme of work which is not covered under the current GD1 allowances.

There is no direct financial benefit to the network to undertake such a programme, and no reason it should do that under business as usual operation. The Project Risk Register can be found in Appendix G with an overview in Section 6.1.4. In summary, the key risks this programme seeks to address are Technical and Operational – understanding the risks associated with the operational and maintenance techniques currently in use on a natural gas network that will be needed for the new hydrogen network.

None of these risks would need to be addressed if the GDNs were to continue to operate the network using natural gas. The rationale for the project is to enable an alternative, low cost and non-disruptive decarbonisation solution for the customer and for GB to meet its carbon commitments.

This next phase of work consists of some degree of capital build, alongside both scientific investigation and practical demonstration. This mix of activities are of a scale beyond NIA funding and, as such, a more significant funding mechanism is required to enable this essential work to happen.

4.4 Involvement of other partners and external funding (Criteria e)

4.4.1 (i). Collaboration that is appropriate to the Project being undertaken

The proposed H21 Project will see the five major gas businesses of GB collaborating on the research to understand, share and accelerate the evidence needed. The existing H21 NIC project has all four gas distribution businesses working in partnership. This next phase of work sees a continuation of that collaboration and, in addition, has National Grid joining the team to lend their considerable expertise and skills to the research.

All five companies are committed to funding an equal share in line with regulatory requirements.

The construction of the micro-grid demonstration network has industry wide benefits and DNV GL has affirmed their commitment to making the facility available to gas distribution networks in a low cost and effective manner using bespoke frameworks. The loop and facility are to include most elements of a gas distribution network and will prove a valuable industry asset for natural gas, hydrogen and conversion training activities.

4.4.2 (ii). The systems or processes the Funding Licensee used to identify potential Project Partners

The Project undertook an internal procurement review for the H21 project. It was concluded that it was essential to continue the next phase of the project with the current expert partners and key personnel to maintain momentum, and to avoid the additional costs and delays, associated with procuring new partners. The project timeline is now largely dictated by the needs of Hy4Heat to deliver the evidence needed for any future at scale trials.

To identify next steps leading on from the current H21 NIC Phase 1 project, a series of meetings, workshops and phone calls were undertaken with all project partners to establish the likely position at the end of Phase 1. With this baseline the previous concept 'Phase 2: Field Trials' was discussed, and along with partners, and accounting for the needs of other hydrogen research work such as Hy4Heat, the scope and deliverables were transformed into the proposal now put forward. Key advice from colleagues within the HSE-SD team and from experts across the industry helped to shape the programme of work and create a series of work packages that support the delivery of evidence required to then lead onto next steps, such as a small-scale community trial.

The project engaged with wider industry to link into the work undertaken through the Hy4Heat programme and SGN H100 particularly to identify opportunities for closer ties and supportive research activities in the next phase of work. This engagement continues to bring in findings from that work and other projects further afield to enable better outcomes from this next H21 project. From a wider community perspective, the team have been in contact with Australia Gas Infrastructure Group to understand their hydrogen research and how the work conducted in the UK and Australia might complement one another. Importantly, collaboration is seen as a key enabler and, as such, has been a central aspect of the existing H21 NIC Phase 1 project. Should this next phase be supported by Ofgem, this open, collaborative approach would continue, to both deliver value for customers and share the learning to a wider community as quickly as is practicable.

4.4.3 (iii). Outline the steps taken to ensure that the Project Partner has put in place systems or processes as set out in point (ii);

The project collaboration agreements between all project partners from Phase 1, these will be extended to include the Phase 2 project. The Project will also utilise appropriate project partners' processes to improve areas such as procurement, construction and on-site safety management systems, and continue to operate under the ethos of continual improvement.

4.4.4 (iv). Evidence of reasonable attempts to collaborate or to obtain External Funding

The project partner DNV GL are contributing towards the project by hosting the extension to the Phase 1b site and providing the videography free of charge. This 4k videography will be used for scientific result analysis as well as knowledge sharing and project updates. DNV GL will also provide site-based conferencing and hosting facilities for knowledge dissemination for a range stakeholders.

DNV GL will additionally complete the fit out of the houses constructed in Phase 1b with boilers, fitted kitchens and appliances, which will be utilised as part of the extended micro-grid. DNV GL will also free issue some of the network fittings for the new Phase 2b design, including valves and pipework.

Where possible we would expect vendors to provide their equipment and resource for testing their equipment free of charge e.g. flow stopping.

Following on from the successful social sciences work in Phase 1, the project team are collaborating with Leeds Beckett University for Phase 2d. This will enable continuity of the learning from Phase 1 through to Phase 2. (See appendix C.8 and D.6)

We are still currently seeking land procurement options for Phase 2b with the intention of offsetting some of the costs to the benefit of the landowner, e.g. peppercorn rent. There may be a requirement to collaborate with another GDN or organisation, e.g. the MOD, if a suitable existing NGN network site cannot be located.

4.5 Relevance and timing (Criteria f)

4.5.1 (i) Why the Problem the Network Licensee is looking to investigate or solve is relevant and warrants funding in the context of the current low carbon or environmental challenges the gas sector faces; and

Over the last two years there has been an ever-increasing momentum behind the use of hydrogen across a wider number of sectors. It is now seen as a highly flexible platform for decarbonisation. Publications such as the Committee on Climate Change (CCC) 'Net Zero – The UK's contribution to stopping global warming', May 2019 and the UK Government publication, 'The Clean Growth Strategy', October 2017 identify a role for hydrogen in the decarbonisation pathway along with the need to demonstrate at scale to deliver the confidence and understanding needed to fully commit to a hydrogen based economy.

The National Infrastructure Commission, National Infrastructure Assessment[28] also recommends that government needs to make progress towards zero carbon heat by:

- Establishing the safety case for using hydrogen as a replacement for natural gas, followed by trialling hydrogen at community scale by 2021.
- Subject to the success of community trials, launching a trial to supply hydrogen to at least 10,000 homes by 2023, including hydrogen production with carbon capture and storage.

In the context of a whole energy system strategy, there is a need to consider the impact of decarbonisation that one energy vector such as hydrogen gas might have on another, in the outlined position above, namely that of power and transport.

[28] National Infrastructure Commission - National Infrastructure Assessment - July 2018

In transport, hydrogen is seen as the primary solution for heavy fleet such as HGVs, trains, buses, as it became clear that battery solutions may not provide the right mix of range, operability and fit to the needs of operators.

Increased utilisation of windfarm power generation capacity at times of low electricity demand harvesting the green power generation through electrolysis could be used to produce green hydrogen. This hydrogen could be used for several applications, including transportation, power generation or injection into the gas network.

The advent of network conversion to 100% hydrogen would enable new markets and services to be established across the energy landscape. By linking the gas and power systems, via electrolysis for instance, it is possible to deliver green hydrogen into the gas network, further supporting decarbonisation by enabling increased penetration of renewable power onto the gas network and, at the same time, enhancing electricity grid stability and resilience.

Similar benefits can be achieved around transport infrastructure, with the GB gas infrastructure becoming the arteries that feed transport fuel to major centres for trains, heavy fleet and cars. This scenario would remove liquid fuel tankers from UK roads, improving air quality and promoting decarbonisation together.

To get to this new hydrogen economy, the appropriate level of evidence must be established, that gives confidence to the UK government and allows the necessary policy levers to be put in place. This round of funding will support our aim to deliver robust evidence, establishing through scientific assessment, practical demonstration and trials, that the repurposing of the GB gas network to convey 100% hydrogen is realistic, credible and can be delivered as outlined in previous desktop research projects such as the H21 LCG and H21 NoE papers.

4.5.2 (ii) How, if the Method proves successful, it would form part of the Network Licensee's future business planning and how it would impact on its business plan submissions in future price control reviews.

It is difficult to be entirely precise at this early stage, as much depends on the outcomes of both the currently H21 NIC Phase 1 project and, if approved, the aims of this new proposal.

The outputs of this work add to the overall hydrogen for heat narrative and library of evidence that is beginning to take shape. As such, it will enable the next steps to be taken to further increase confidence and enhance learning and processes.

The most ideal outcome is that all components of the GB gas distribution network (operating at less than 7 bar), are shown to be capable of safely conveying hydrogen with no depreciation in the risk of safety. In that context, future business planning will focus on the staff resources required to deliver an ever-increasing scale of trials, eventually moving to full scale roll-out. However, this is a very optimistic perspective and the more likely outcome is that certain components are shown to perform at below the optimum level of performance and as such would require some form of mitigation to allow the deployment of hydrogen to occur.

Consideration can also be given to those elements of capital work identified as necessary to manage any future roll out programme. These can be considered with a view to front-loading work in time for the eventual introduction of hydrogen into the network, for example, installation of sectorisation valves during the mains replacement programme that would be essential during the hydrogen conversion process. Another branch of business planning would be to assess the impact of the mains replacement with the use of insertion techniques rather than open cut replacement, leading to a reduction in network capacity, potentially causing hydrogen pinch points.

Any work required would be fully costed and planned such that it minimised any impact on customer bills while delivering the required functionality to support decarbonisation at the right time. This would be achieved in the normal manner through clear network planning, accurate project plans and costs and supported by tight programme management.

Section 5. Knowledge dissemination

This Project will conform to the default IPR arrangement set out in the Gas NIC Governance Document.

The GB Gas Distribution Networks (GDN) and partners are committed to sharing the knowledge generated by this Project. Its purpose is to provide urgent and essential evidence to facilitate optimised UK government policy decisions on decarbonising heat in the early 2020s. More widely it will inform the supply chain of stakeholders, in both the natural gas and hydrogen industries, of the viability of a 100% Hydrogen conversion option. Wider still the Project will be used to inform international opinion and potentially international energy policy. Fundamentally the Project will provide quantified evidence to the public on the difference in risk between a 100% Hydrogen gas distribution network and the current natural gas network.

5.1 Learning generated

The purpose of the Project is to provide unique and referenceable data for the GB gas industry and other stakeholders. The learning generated from this Project will:

- Validate all industry procedures applicable to the below 7 bar systems.
- Develop a scientific approach to extrapolate findings across GB infrastructure.
- Develop the process, relationships, assurance and techniques to create a conversion blueprint suitable for use within the Hy4Heat and H100 projects.
- Deliver the supportive evidence required to inform any decision to move to occupied community trials, through the BEIS Hy4Heat programme.

Without this research there will be significant gaps in the knowledge and evidence required to inform competency, skills, process, network management requirements and in the understanding of how to realistically convert networks from natural gas to hydrogen whilst ensuring continuity of supply to the customer.

This knowledge and learning will be relevant to the whole GB gas industry. The fundamental properties of hydrogen, types of GDN asset and the consequences of release will not change significantly in different areas of the country.

Throughout the H21 NIC Phase 1 project, the project team continuously communicated learning generated from the Project through a variety of channels. This approach will continue during this Project building on relationships with existing, as well as new, stakeholders ensuring that they remained engaged and informed with the progress of H21.

The major aim is to gain greater understanding on the specific safety risks for hydrogen with this Project focusing on operational procedures. Key areas of generated learning which will be applicable to GB GDNs and the GB NTS include:

Operational procedures: Operational evidence from Phase 2a – Appraisal of Network Operations will provide unique evidence relating to the technical and operational issues associated with 100% Hydrogen. It will also allow an understanding of what changes (if any) may be required to operational procedures for a 100% Hydrogen conversion and provide direction for future studies in this area.

Unoccupied trials: These will provide comparative safety-based evidence for 100% Hydrogen conversion in a real environment. This will check that the extrapolation of results across GB network assets was accurate, that tests undertaken in controlled environments can be used to accurately predict real-world environments, and that operational procedures (repairs, flow stops etc.) can be safely and effectively carried out in real world environment. This will ensure that all stakeholders, including the Duty Holders and the HSE, can have confidence in, and ultimately sign-off, the Safety Case for moving onto the occupied trial phase.

Quantitative Risk Assessment (QRA): The H21 Phase 1 project is currently updating the existing gas network QRA for transportation of hydrogen. Results from H21 Phases 2a and 2b would develop this further to update and refine the evidence feeding the QRA. Additionally, integration with the Hy4Heat QRA and liaison with the H100 QRA team will be undertaken, which will enable a holistic view for the general public.

Manufacturer and supplier information: Information will be provided to relevant manufacturers and suppliers on the impact on performance of equipment, components and fittings as part of the Project. Working with the manufacturers and suppliers of different assets, the Project will identify any areas of concern and potential solutions.

All information will be captured by the work programme and recorded in the monthly progress reports produced for the monthly Board meeting. This will act as the basis for dissemination. The project partners are confident that the quality of the captured learning will be substantial enough to generate an understanding of the major hazard risks associated with the conversion of the distribution network to 100% Hydrogen.

5.2 Learning dissemination

The project partners recognise the importance of effective knowledge dissemination and learning and are committed to it. The Project team includes all the GB GDNs and the GB NTS. The Steering Board that was established during the H21 NIC Phase 1 project will continue to meet on a quarterly basis to ensure effective and efficient knowledge dissemination (see Appendix E: Project Governance and Organisational Structure).

The Project has support across the wider gas industry and is building on this support and the 'H21' brand. During the H21 NIC Phase 1 project a comprehensive knowledge dissemination process was established. This process will continue throughout this Project to ensure continuity of the dissemination of knowledge generated through H21 projects.

5.2.1 Stakeholder engagement

There is a wide range of stakeholders for whom data, knowledge and learning generated from this Project could have significant impacts. As part of the H21 NIC Phase 1 project, the following stakeholder groups and our reasons for engaging with them were identified:

Stakeholder group	Why we engage with this group
Gas Customers (GC)	To be open and honest about all aspects of the Project and conversion, including the reasons why it is taking place and the cost and safety implications associated with it. This will allow an informed decision to be made with regards to hydrogen conversion.
GDNs & Associations (GA)	To ensure that all GDNs, as collaborative partners, and associations are fully informed on the progress and results of the Project. With this information the GDNs and associations can support the Project and subsequent policy decisions. In addition to this, the industry-wide process of updating and putting in place the standards and training that a 100% Hydrogen conversion may require can begin.
Ofgem (O)	To provide regular updates on the Project to provide confidence that the funding is being used appropriately to ensure that our customers are receiving value for money. As the regulator, Ofgem need be part of the H21 journey to ensure they can confidently approve the conversion, as well as fund and/or source a mechanism for funding the conversion.
HSE (HSE)	To provide full transparency of the H21 project and its progress and ensure that the Project remains within the Health and Safety at Work Act at all times. Continue the successful collaboration with the Project in order to produce and agree on the safety course required for 100% Hydrogen conversion, which will be vital to future policy decisions.
Local Authorities, National Government	To gain support and exposure for the Project locally, nationally and internationally providing influence/lobbying into UK Government for policy decisions. To ensure that the first

and International Government (GOV)	conversion areas are ready and willing to assist with the conversion.
Gas Shippers and Suppliers, Carbon Capture, Hydrogen, Energy, Clean and Green Energy (CGE)	To engage with all parties to ensure renewed support, collaboration and research in their respective fields in order to provide strength and weight to the Project and its implications. Additionally, this will also enable further influence and lobbying of UK Government for policy decisions.
Appliance Manufacturers (AM)	To promote research into hydrogen compatible appliances and ensure that these are available and cost effective prior to point of conversion. Further fostering a close relationship with HyDeploy to work collaboratively on crossover sections of the projects and ensure that the projects are delivered in tandem for a dual approach to achieving positive policy decisions.
Engineering and Consultancy (EC)	To prepare the industry for hydrogen conversion allowing for future planning strategies with regards to addressing the skills shortage, adapting current processes and approaches, and allowing time to invest in the resources required for conversion.
Financial Investors (FI)	To provide updates on the Project and its implications locally, nationally and internationally, to the environment and economy, in order to attract additional funding for further research and/or conversion.
Universities, Research Companies and Educational Bodies (RE)	To disseminate the latest information regarding H21 allowing the education sector to provide current information whilst educating. This will encourage further research and support for a 100% Hydrogen conversion.
Internally (Int)	To inform of progress of the Project in order for NGN staff members to act as H21 ambassadors.
International (I)	To generate international interest, support sharing best practice and encourage delivery of outstanding evidence quicker across a global community in order to provide enhanced lobbying back into UK Government.

Effective engagement with some of these groups has been a key part of the work already undertaken as part of the H21 Leeds City Gate (LCG), H21 NIC Phase 1 and H21 North of England (NoE) projects and referenced within this document (see Appendix J: Stakeholder Engagement). Real routes of communication have already been established and knowledge and learning shared. This Project will look to build directly on these relationships and extend across the wider stakeholder group.

5.2.2 Knowledge dissemination process

The knowledge dissemination process established in the H21 NIC Phase 1 project ensured appropriate dissemination of targeted knowledge to key stakeholders. This process requires all information generated by the Project to be requested for release. Requests are made by submitting a knowledge dissemination form where details about the information to be released, the intended date of its release, the stakeholder groups that the information is intended for and the format the information will be released in are recorded. Knowledge dissemination requests are discussed at the Project Board meetings and, if approved, the H21 Programme Director presents the request for discussion with the Steering Board. Approval by the Steering Board ensures that the knowledge is disseminated as detailed on the knowledge dissemination form; if approval is not granted the requestor may amend their request. However, until approval is granted no information can be released or discussed with external stakeholders. This rigorous process is critical in order to ensure that the correct information is managed as part of the Project and during each of the project stages. This Project will see a continuation of the use of the knowledge dissemination process.

5.2.3 Means of dissemination

A communications plan will be developed in order to effectively execute the stakeholder engagement and knowledge dissemination process.

The project team engages with a wide range of stakeholders and expect to continue to build on these relationships. To be effective, the communications plan must include a wide range of methods that can adapt to the diverse requirements of each audience. To ensure that clear and consistent interpretation of data is made, all public communication will be approved by the H21 Programme Director and the Steering Board in line with the knowledge dissemination process detailed above.

It is also important that the profile of the H21 NIC Phase 2 project is maintained to ensure industry momentum generated throughout the previous H21 projects (H21 LCG, H21 NIC Phase 1 and H21 NoE) is maintained. As such the Project will use a variety of channels of dissemination as shown below:

Knowledge sharing events	Throughout the H21 NIC Phase 1 project the team attended and presented at several knowledge sharing events that were hosted both locally and nationally. These events took the form of meetings, workshops and round table events where knowledge sharing, and collaboration were encouraged. Attendance at these events and sharing of the knowledge generated through the Project will continue during this Project.
Project Website	An extensive website was developed during the H21 NIC Phase 1 project; this will be expanded to incorporate information regarding and generated through this Project. The website is accessible and informative for all stakeholder groups and contains information on all the current and previous H21 projects including downloadable Executive Summaries of project reports and H21 films on the H21 LCG, H21 NIC and H21 NoE projects.
Open day events at the Phase 2a site	Targeted open day events will be held at the Phase 2a site with a range of stakeholder groupings. These site visits will enable stakeholders to witness the trial and engage with the wider project team.
Social media, general and industry trade media	The H21 website will be supported by wider social media presence on Twitter among others. Excellent engagement with wider media outlets has been achieved during the previous H21 projects (H21 LCG, H21 NIC Phase 1 and H21 NoE). This will be continued throughout the Project.
Conferences	Information will be presented at the annual gas networks innovation conference, as well as other gas and low carbon conferences both in the UK and internationally.
Publications	Building on the success of the previous H21 projects (H21 LCG, H21 NIC Phase 1 and H21 NoE) further project specific literature will be developed to communicate the Project to the various audiences. This will include industry, trade and academic journals, as well as brochures and handouts.
Industry Networks	Learning from the Project will be shared with the industry networks, such as IGEM, the ENA R&D working group, the EUA and the Hydrogen Transformation Group.

Close out report and progress films	At Project completion a comprehensive close out report and progress films will be publicly available to all stakeholders via the website as was the case with the previous H21 projects (H21 LCG, H21 NIC Phase 1 and H21 NoE).

In addition to communications in line with the above a specific relationship for communication will be developed with the Hy4Heat and H100 teams.

5.3 IPR

The Project will comply with default IPR provisions. The purpose of the Project is to generate safety data for the conversion of the distribution networks to 100% Hydrogen. Since this data will be common to hydrogen in gas networks across the country there is no intention or opportunity to exploit arising IPR commercially in GB. Copyright will exist on the reports produced as part of this work, but they will be published in the public domain where required for effective knowledge dissemination.

Background IPR, such as that within equipment supplied for the purposes of executing the Project (e.g. measurement devices), will remain owned by the suppliers as commercial products. This will include the project partners' background IPR in their existing quantitative risk assessment software and models. The testing and analysis work carried out in the Project will generate knowledge of hydrogen properties and release consequences for comparison with those of natural gas. DNV GL and HSE-SD have carried out extensive tests with natural gas in the past, the results of which will constitute background IPR where used in the Project. The results of any wholly novel tests with natural gas carried out as part of the Project will be foreground IP. No additional software capability will be developed as part of the Project. Any quantitative risk assessment procedures that are developed as part of the final recommendation will be software agnostic to allow ready implementation by any gas network operator.

Section 6. Project Readiness

6.1 Evidence of why the project can start in a timely manner

GB Gas Transmission, Gas Distribution Networks (GDNs) and all the project partners are confident in the ability of this project to deliver the objectives in a timely manner. This is due to the high level of technical preparation, quality of expertise and extensive stakeholder engagement undertaken to date which underpins this proposal. The key factors ensuring a timely start to the project are summarised below:

Network Innovation Allowance work to date: Further to the work done on the initial phase of the H21 NIC bid submission, there has been considerable work on the thought process for addressing the H21 NIC Phase 2 Network Operations project.

In addition to H21 Phase 1, the H21 NIA Field Trial Design project is being implemented and has progressed alongside the preparation of this bid and throughout 2019. The primary purpose of the H21 NIA Field Trial Design project is to ensure project readiness should the H21 NIC Phase 2 bid be successful. This has been achieved by providing confidence in costs and informing the master testing plan (what, how and why testing is being undertaken). In addition, the conceptual design for the H21 NIC Phase 2a micro-grid is complete and the detailed design will be finalised at the start of the Project.

Stakeholder Engagement: Throughout H21 NIC Phase 1, there has been a wide-ranging and thorough level of stakeholder engagement. This has included:

- Local and National Government including various MPs, Bradford, Middlesbrough, Gateshead Councils and WYCA.
- Local Development such as Tees Valley Combined Authority.
- International, including Eurogas, Gas Regulator in Singapore, Chief Scientific Advisor to Australia and Australian Gas Infrastructure Group and the Hong Kong Technology Institute
- The wider energy sector via over 36 conferences.
- Advisory bodies and institutions, including the Committee on Climate Change, Energy Utilities Association, Energy Networks Association, Institute of Gas

Engineers and Managers, The Energy Systems Catapult/Energy Technologies Institute, Policy Exchange, Carbon Connect, Energy Research Partnership, Carbon Capture and Storage Association and the European Zero Emissions Panels.
- Other hydrogen projects, including Hy4Heat, H100, HyNet, HyDeploy, etc.

A list of key stakeholder engagements can be found in Appendix I: Project Partners.

This extensive engagement has established the foundations of this proposal, based on galvanised opinion across the supply chain, leveraging expertise while focusing on the critical evidence gaps without duplicating effort. This has ensured that the bid is highly credible from the start with the upfront benchmarking and national and international stakeholder engagement.

Another important area of engagement has come from other hydrogen projects either within the GDNs, National Grid (NG), government or third parties. Two key interfaces now exist with the BEIS £25m Hy4Heat programme and the SGN H100 project. Hy4Heat is of particular significance as it directly connects to the work in both H21 and H100, being downstream of the Emergency Control Valve (ECV).

The H21 team have representation on the newly formed Hydrogen Transformation Group (HTG). The HTG Executive Steering Board will provide guidance and approval for the transformation of the gas networks to 100% hydrogen, including financial control and approval, strategy approval and receiving progress reports. The Executive Steering Board includes Director/CEO-level representatives from each of the GDNs (Northern Gas Networks, Cadent, Wales & West Utilities, SGN,) and National Grid, Ofgem, BEIS, HSE, ENA, IGEM, BU-UK and appliance manufacturers. ENA has defined the gas decarbonisation pathway, as shown in Figure 6. ENA: Gas Decarbonisation Pathways.

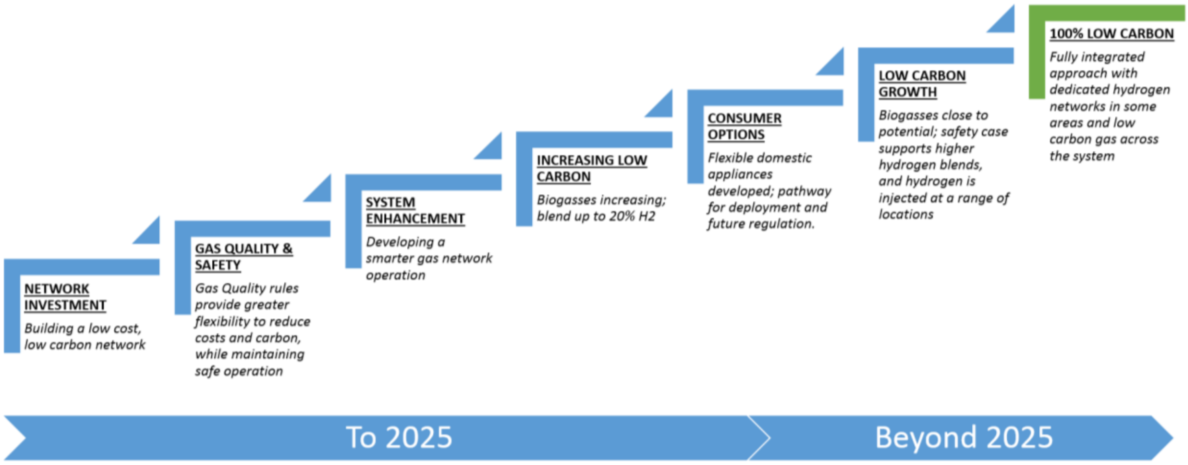

Figure 6. ENA: Gas Decarbonisation Pathways[29]

At local level across the various councils of West Yorkshire and Tees Valley Combined Authority (TVCA), there is significant support and appetite to continue the H21 concept (see Appendix K: Letters of support).

During the H21 NIA Field Trials project, the team has worked closely with the local authorities, and the MOD to locate a suitable site for Phase 2b – Unoccupied Network Trials. All of the GDNs have also been involved in trying to locate potential sites for unoccupied trials on their existing networks. All have actively supported the remote trials stage of the project to ensure minimal delays and enhanced value for money for gas customers. The NIA project is also providing the design for H21 NIC Phase 2a micro-grid in order to reduce the Phase 2 programme (see Appendix D: Project Technical Description for more detail).

Unique expertise: To ensure continuity between H21 NIC Phases 1 and 2, it is proposed that the original team of project partners is used. This project team is drawn from some of the most knowledgeable and experienced organisations and individuals in the UK with an international support network of industry leading experts. This has

[29] 'Gas Decarbonisation Pathways', Energy Networks Association, February 2019

ensured the project has the proven skills portfolio to deliver, with a strong focus on value for money and ensuring minimal spend to solve the problem statement. Continuation of their contractual arrangements are already agreed in principle, avoiding any delays in project execution following subsequent award of the NIC.

6.1.1 Project plan

A detailed project plan is shown in Appendix F: H21 Phase 2 Programme. The four project phases are as follows: Phase 2a – Appraisal of Network Operations, Phase 2b – Unoccupied Network Trials, the associated Phase 2c – Combined Quantitative Risk Assessment (QRA) modelling requirements and final reporting as well as Phase 2d – Social Sciences. The programme has been developed collectively by the project partners and has undergone an iterative review process to ensure agreement on both deliverability and responsibility. This has been achieved by targeting a series of outputs that further underpin learning and secure key components of the safety related evidence required and that are deemed essential for any future policy decision.

The project plan is assumed to commence in January 2020 and is designed to complete at the end of 2022. The GDNs will add their year one contribution to the NIC project bank account to bridge any gap between delivery of NIC funding provision (April 2020) and the January 2020 start date. This will ensure there are no delays to project execution. As with any major project, governance will be in place to ensure progress is monitored via the regular review process explained in Appendix E: Project governance and organogram.

6.1.2 Project Management and Governance

The aim of the Project structure is to manage and deliver the Project safely within budget and programme. It is designed to provide the Network Licensee the level of control required to meet the requirements of the Ofgem Governance Document, as well as the governance requirements of the partners, specifically DNV GL, who are the operators of the Spadeadam, and the Health & Safety Executive Science Division (HSE-SD).

The Project management and governance is summarised in the two diagrams found in Appendix E: Project governance and organogram.

The GB GDNs and NG have a well-developed and proven project collaboration agreement, which has formed the basis for previous NIC projects to date. This agreement is the same as H21 NIC Phase 1 used for the primary project partners and will form the basis for this project.

The governance framework is in place from Phase 1, to ensure appropriate oversight and control over key decisions and to delegate authority for scope delivery to a Steering Board. The Steering Board will comprise of representatives nominated by each of the collaborating GDNs, NG and the primary project partners. The Chair of the Steering Board shall be the H21 Programme Director for NGN. Should the Chair not be available, they shall delegate to an H21 Senior Project Manager.

The Steering Board will meet on a quarterly basis to review project progress reports, performance against budget, key project risks and material issues. The rules of the Steering Board will be set out in the project collaboration agreement and are summarised in Appendix E: Project governance and organogram.

The H21 Programme Director is accountable for the successful allocation of milestones and allocation of stage funding under the NIC allowance. The Project nominees from the other GDNs shall report progress to their own Executive Committees.

Project Management is provided by a multi-disciplined project team (see Figure E1: Project organogram, Appendix E), responsible for co-ordinating the day-to-day operations of the project, coordinating and reporting to the Steering Board, and acting upon decisions, with relation to budget management, and submitting requests for Milestone completion and sanctions to progress to subsequent project stages.

Project Board meetings of the participants will be held monthly. More detail on the Project Board in Appendix E: Project governance and organogram.

Due to the nature of the H21 NIC Phase 2a – Appraisal of Network Operations, testing will be required at the DNV GL managed Spadeadam site, which will be overseen by

HSE-SD. Phase 2b – Unoccupied Network Trials will be overseen by DNV GL and HSE-SD.

To provide an appropriate level of governance and agreement of the test plans both DNV GL and the HSE-SD will oversee. Furthermore, both partners will have a presence at each testing operation to confirm that tests are undertaken in line with agreed methodology and to ensure credibility of results.

DNV GL and HSE-SD will also be involved in Phase 2C – Combined QRA, which includes a review of the QRA integration, modelling and attending key meetings.

6.1.3 Project partners, contractors and team

The GB GDNs and NG have built a project team to include experienced and expert companies and individuals that have either been involved with Phase 1 of the project or other key hydrogen projects. Additional company summaries and CVs of key individuals can be found in Appendix I: Project Partners.

Project partners have been categorised as primary partners or support partners. Primary partners (DNV GL and HSE-SD) are responsible for the delivery of key aspects of the Project. Where needed, support partners add specific strategic hydrogen and gas operational equipment advice to the project team to ensure validity of results, value for money, support in knowledge dissemination and to provide general challenge and review to the Project Board and Steering Board meetings.

This Project is a true collaboration between **Northern Gas Networks**, **Cadent Gas, SGN**, **Wales & West Utilities** and **National Grid**. Further to the original H21 NIC Phase 1 project, NG have joined Phase 2 as a project partner and sponsor. All partners bring their expertise and profound experience of the gas network to the project, and between them have undertaken numerous NIA and NIC projects in the past including HyDeploy, H100 and HyNet. The Project's primary and supporting partners and their roles are summarised below.

DNV GL (primary partner): DNV GL's UK gas consulting business has a common history with the GDNs since, like the GDNs, it was formerly part of British Gas. DNV GL still employs many of the staff responsible for the leakage testing programme developed and executed throughout the 1990s and, to date, have been invaluable in advising on the testing programme, specifically avoiding unnecessary testing where possible. They are the operator of the Spadeadam Testing and Research facility, on the border of Cumbria and Northumberland, and have over forty years' experience of carrying out hazardous testing at large scale, quantitative risk analysis, and computer modelling. They will plan and oversee the experimental programme at the Spadeadam site, as well as providing a reviewing and support function on Phase 2b – Unoccupied Network Trials. DNV GL will also have primary responsibility for the QRA and updating of the existing computer modelling platform used to extrapolate results across the GDN asset base.

Health and Safety Executive Science Division (HSE-SD) (primary partner): HSE-SD is one of the UK's foremost health and safety experimental research establishments. They understand the issues that the HSE need to see addressed in this project. This experience significantly de-risks the project by ensuring that the relevant evidence base is understood from the outset and ensures close and effective engagement with the HSE throughout the process. HSE Science Division will lead on collating available information from literature, modelling, experimental work and demonstration into a single narrative on the basis of safety of procedures and network components when operating the network with 100% hydrogen as well as any oversight of QRA and field trials as included in the bid.

The Leeds Sustainability Institute (LSI) at Leeds Beckett University: The LSI at Leeds Beckett University is a team of academics and practitioners with over 20 years' experience of research and consultancy in sustainable energy use. The team includes psychologists, data scientists, environmental scientists, architects, design specialists, construction managers and building performance researchers. The LSI also hosts Engineering Doctorate students, the majority of whom come from leading organisations in the UK energy and construction sectors. The LSI has an excellent track record of working on national projects on energy-related projects, such as the Carbon Control and Comfort project, a 3-year research project funded by the Engineering and Physical

Sciences Research Council (EPSRC), and behavioural change that will bring vital academic research input to the project.

6.1.4 Project Delivery Risk Assessment and Mitigation

The Project will be managed using a structured approach to project delivery risk. During the development of the project a risk register has been drawn up as shown in Appendix G: Risk Register, which identifies risk, risk management and mitigation plans.

A standardised approach is used for the project, where risks are categorised and assessed in terms of likelihood and impact. Likelihood is assessed on a scale from 1 to 5, from impossible to certain, and impact assessed between 1 and 5, from low to disastrous. Mitigation measures against each risk are identified and actions proposed by the key project team members. The risk is reassessed based on the mitigation measures being put in place. This tool will be used proactively to manage the Project throughout the delivery phase, with clear responsibility for each action and risk status. It will be updated regularly throughout the Project and will provide the basis for the monthly report.

The H21 NIC project risk is grouped into three main categories of risk; namely health and safety risks, technical delivery and project risks. The risk register has been generated adopting a 5x5 risk rating.

The health and safety risks are primarily around the construction, delivery and undertaking of the first two key phases, Phase 2a – Appraisal of Network Operations and Phase 2b – Unoccupied Network Trials. As these are all practical and operational testing, the risks are potentially high although – with the necessary controls and mitigations in place – these will be managed to ALARP (As Low As Reasonably Practical). It is vital that on site controls and management are effective in the delivery of the programme.

The technical risks associated with the project predominantly relate to data. The importance of data quality is critical. Having the appropriate instrumentation available is both a key factor and a risk. While some of the instrumentation is already in use for similar types of projects for measuring data, such as Phase 1, further investigation will also be undertaken at the commencement of this project. There will be the need for detailed design and planning of the sites and this has already been advanced by the H21 NIA Field Trials project in which the sites will be designed and approved through a design assurance process, following the industry guidelines.

Project risks includes the delivery, duration and cost of the project. These risks will be managed throughout the duration of the project, as outlined in Section 6.1.2 and Appendix E: Project governance and organogram. An additional risk is the engagement of stakeholders and the importance of stakeholder management through the project; this will be supported with a knowledge dissemination strategy as defined in Section 5: Knowledge dissemination.

6.1.5 Interface with other Innovation projects

Over the last two years, the recognition of the role hydrogen could play in decarbonising heat has grown substantially, with a range of projects being undertaken.
The H21 NIC Phase 2 project forms part of a wider roadmap, being developed by HTG, working towards deployment of hydrogen on the GB gas network.

All GDNs and the Transmission Operator are pursuing low carbon gas solution with a strong emphasis on hydrogen. There is also close engagement with BEIS projects such as Hy4Heat, which seeks to provide the downstream evidence base for conversion to 100% hydrogen.

H21 NIC Phase 2 has been established directly from the H21 NIC Phase 1 project and based on the 'Executing the H21 roadmap' document[30]. This NIC project is central to unlocking a long-term future for low carbon energy (heat, power, light and transport) by utilising hydrogen gas alongside growing the low carbon economy.

[30] Executing the H21 roadmap

The development of a hydrogen economy around the role of hydrogen for heat will also hold the key for the distribution of hydrogen for transport, including the recently announced hydrogen train trials in the UK.

H21 NIC Phase 2 will interact and directly complement the BEIS £25m 'Downstream of the ECV' innovation programme. Designed to deliver within similar timescales, these two world-first innovation programmes will ensure the critical aspects of the outstanding critical evidence for a 100% hydrogen conversion to decarbonise heat is provided effectively and efficiently. This is key to unlocking an optimised future policy decision on heat in the interests of gas customers and the environment. This project also views the H100 work undertaken by SGN as a significant comparator and natural interface to accelerate learning and minimise cost to the customer by complementing the work undertaken in each and therefore avoiding duplication.

Finally, H21 NIC Phase 2 project will be centrally coordinated from the H21 project office, within the NGN facility in Leeds. This office has already established national and international links (e.g. Equinor, Australia, Eurogas and Hong Kong) via stakeholder engagement activities and hydrogen-specific NIA projects including:

- H21 – Strategic Modelling Major Urban Centres
- H21 – Domestic Metering
- H21 – Alternative Hydrogen Production and Storage Methodologies
- H21 NIC – Phase 1

These relationships will be utilised to ensure international best practice and benchmarking, knowledge dissemination and enhanced global lobbying to support the development of community trials – following the BEIS and H21 NIC programme completions.

6.2 Evidence of the measures a network Licensee will employ to minimise the possibility of cost overruns or shortfalls in Direct Benefits

6.2.1 Budget Development

The starting point for the cost plan is the careful design of the overall programme. This ensures that not only are the technical activities accounted for, but that important facets such as communications and consumer engagement are properly considered and costed. The programme and costs have been developed collaboratively and iteratively by all the project partners, drawing on the significant body of technical work from the H21 NIC Phase 1 and H21 NIA – Field Trial Design, as well as the specific and unique expertise and historical background from the partners.

Collective development and agreement by all partners were established on the minimum testing requirements that would be essential to solve the problem statement, i.e. H21 NIC Phase 2a and Phase 2b and the detail thereof (see Section 2: Project Description and Appendix C: Gap Analysis). Once this was finalised and agreed, a detailed iterative costing exercise was undertaken to establish a bottom-up cost breakdown, based on levels of effort for individual activities. For the existing project partners the rates were based upon the phase 1 costing plus inflation. These rates will be fixed for the duration of the NIC project.

Costs associated with site construction for the H21 NIC Phase 2a and Phase 2b were established utilising NGN expertise to provide estimates against preliminary site designs – these were also sense-checked and agreed as appropriate with the respective site owner partners. These estimates are based on business as usual practices within the networks and are considered minimum cost whilst ensuring achievable delivery.

Estimates for specialist or specific items – for example hydrogen supplied to site – were provided utilising the expertise and wider connections of the project partners and/or appropriate benchmarking against other network projects, for example site security for unoccupied trials.

The consolidated costs have been reviewed by the project partners and are summarised in appendix H – Cost Breakdown. In particular, the detailed risk register (Appendix G) for the Project has been reviewed to identify areas which require allowances to be made against specific activities. By these means, and through an internal review process, there is confidence that not only is the scope well defined and comprehensive enough to deliver the requirements of the project, but that the associated costs are accurate and robust.

The core team costs, including HSE-SD & DNV GL for the phase 1 NIC were budgeted until June 2020 and therefore have been removed from the make-up of the costing for this bid to avoid duplication.

6.2.2 Budget Management

The project will be carefully managed to ensure that it delivers to budget. This will be overseen by the Steering Board.

The Project Manager will consolidate and track project costs from the partners and subcontractors. These will be provided as part of the wider monthly project reporting process to the H21 Programme Director for sign off.

NGN already has in place the governance processes to manage a separate NIC account, and to provide the necessary traceability of invoices and payments made.

Budgets will be reviewed quarterly by the Steering Board, to give forward visibility of costs and the opportunity to proactively address potential deviations from budget.

6.3 A verification of all information included in the proposal (the processes a Network Licensee has in place to ensure the accuracy of information can be detailed in the appendices)

The data provide in this proposal has been developed by all project partners as an integrated design managed by QEM Solutions. All of the GDNs and NG have reviewed and accepted the content of this bid document.

Scope: This was developed iteratively in conjunction with the project partners, building on, and informed by, the work undertaken in the H21 NIC Phase 1 and H21 NIA Field Trials.

Technical Programme and Budget: The overall technical programme was developed by the project partners and the current H21 NIC Phase 1 project team.

Phase 2a – Appraisal of Network Operations: To be achieved via HSE-SD facilitated workshops and seminars on current operational and maintenance procedures with key partners and gas operational personnel (as defined in Appendix D: Detailed Project Description) and then agreed across the GB GDNs, NG and primary partners.

Phase 2b – Unoccupied Network Trials: Defined and agreed across all project partners.

Phase 2c – Combined QRA: Defined and agreed by DNV GL in discussions with Hy4Heat.

Phase 2d – Social Sciences: Defined and agreed by Leeds Beckett University in discussions with NGN and liaison with HyDeploy and Hy4Heat.

6.4 How the project plan would still deliver learning in the event that the take up of low carbon technologies and renewable energy in the trial area is lower than anticipated in the Full Submission

This Project is globally significant and will provide valuable and entirely new learning for the UK and worldwide gas industry. Whilst the carbon savings and financial benefits to gas customers will only be achieved through a subsequent conversion to 100% hydrogen, the learning is not dependent upon the take-up of the option. In the event that the conversion to 100% hydrogen is delayed, then this project will still contribute useful data for knowledge dissemination on network operations. There will also be some learning that could be directly utilised for the HyDeploy project.

The H21 suite of projects will provide the critical safety evidence to unlock significant benefits to UK gas customers, the UK economy and the global climate challenge. The benefits of such a conversion are extensive and can be quantified. However, they cannot be realised without this Project providing policy makers and gas customers with the confidence to make and support such a major conversion decision.

6.5 The processes in place to identify circumstances where the most appropriate course of action will be to suspend the Project, pending permission from Ofgem that it can be halted

The Project has been carefully planned and reviewed by the partners for deliverability, so project suspension or termination is considered unlikely. As part of the pre-bid process, the key project partners held several workshops to discuss the scope of the project, as well as key demonstratable results within the budget and timescales.

However, the progress on the project will be constantly reviewed and assessed by the Steering Board, both quarterly and at Project Board meetings. Other than for general project delivery reasons as identified below, the only additional foreseeable reason to halt the project would be the identification of a 'showstopper' in relation to a 100% hydrogen conversion option. A 'showstopper' could be, for example, the identification of an increase in risk for 100% hydrogen relative to natural gas that would be considered unmanageable in terms of gas distribution of 100% hydrogen. This is considered highly unlikely by all project partners.

The Steering Board will have the power to suspend the Project if:

- Insufficient progress is being made compared to the project plan.
- It cannot be delivered within its budget and additional funds cannot be raised.
- Risks are identified which cannot be mitigated and make delivery of the Project objectives unlikely. (More detail on the role of the Steering Board in given in Appendix E: Project governance and organogram)

After any suspension, Ofgem will be approached to discuss and agree termination of the Project. Under the terms of the project collaboration agreement, specific provisions are defined for dealing with termination of the work in this event. Upon closure, detailed observations and learning will be communicated across the stakeholders to clarify the issue raised and reasons for early closure.

Section 7. Regulatory issues

The Network Licensees will not require a derogation, licence consent, licence exemption or change to current regulatory arrangements in order to deliver the project. The project team has considered the following as part of the project design to confirm the accuracy of this statement.

Regulations/Uniform Network Code (UNC): The H21 Leeds City Gate (LGG) project identified in Section 8 (p268) the extent of the deviations required to both the Gas Act and UNC should a full conversion to 100% hydrogen take place. The key points were:

1. The Gas Act 1986:

Section 48 of the Gas Act defines gas:

"gas" means—

(a) any substance in a gaseous state which consists wholly or mainly of—

(i) methane, ethane, propane, butane, hydrogen or carbon monoxide;

(ii) a mixture of two or more of those gases; or

(iii) a combustible mixture of one or more of those gases and air; and

(b) any other substance in a gaseous state which is gaseous at a temperature of 15°C and a pressure of 1013.25 millibars and is specified in an order made by the Secretary of State.

This means that a hydrogen network could be included within the scope of the Gas Act.

2. The Uniform Network Code / Gas Transporters Licence:

The Gas Transporter Licence is issued under Section 7 of the Gas Act and permits the conveyance of gas. Under their licence, each Transporter must conform to the Uniform Network Code. The UNC is limited in scope to natural gas and does not include hydrogen. Although this definition could be changed, a major review of the UNC would be required to identify any consequential impacts.

The Project will not convert any part of the distribution network which supplies natural gas to customers and will therefore not be 'transporting' hydrogen gas. Phase 2a Appraisal of Network Operations, will be conducted on a test network located on a secure test site (DNV GL's Spadeadam facility) under the local rules for operation of the site. The Phase 2b – Unoccupied Network Trials activities will be managed under a safety management system developed as part of the Phase 1a and 1b work. They will be temporary in nature and conducted on unoccupied and secured sites with no effect on customers, therefore the Gas Safety (Management) Regulations, the UNC and the gas transporters licence are unaffected. No change is required to the licence.

Consumers: No live, occupied trials are included in the project, and so there will be no interruptions to gas supplies or other impacts on consumers. These field trials will be undertaken on in-situ abandoned mains with no customer connections. The purpose of these trials is to confirm the results of the evidence gathered in the background testing, providing confidence to the duty holders to move to the community trials by ensuring a suitable and sufficient safety case can be submitted and agreed with the HSE.

The H21 NIC will not affect 'downstream of the ECV' and will not affect customers' gas supply.

Industry Policy and Procedures: The project is designed to increase knowledge of what constitutes good practice, which will later inform the development of industry policies and procedures for hydrogen. Good practice will be observed in the design and execution of the test programme. The test equipment designs will be independently design-assured using the principles of the gas industry's G17 process or other site processes for test site activities. Task risk assessment and safe control of operations procedures will be observed at all test locations to ensure safe systems of work. All partners have management systems which are independently certified under ISO 9001, OSAS 18001 and ISO 140001 for quality, safety and environmental performance, which will be applied in full during the execution of the work.

The H21 NIC will solve the problem *statement* and allow progression of a policy decision on hydrogen for heat and live trials (upstream and downstream of the ECV). Live trials would require changes to regulations and industry procedures, including the Uniform Network Code documents, secondary legislation (for example, GCoTER – Gas Calculation of Thermal Energy Regulations) and a range of other industry-specific documents. Whilst these amendments are out of scope of this project, the H21 NIC, coupled with the BEIS-led Hy4Heat programme, will provide significant amounts of the evidence required to allow these amendments to take place.

Furthermore, other existing NIC projects such as 'HyDeploy', 'H100', 'Future Billing Methodology' and the 'Opening up the Gas Market' (completed) will add further evidence and, as importantly, establish the methodology for amending these documents in future.

Health and Safety Executive (HSE): the HSE do not own the safety case for gas distribution network operators; these are owned by the GDNs themselves. The HSE ensures compliance with this safety case. However, any significant change to the safety case, such as to convert the GB GDNs to 100% hydrogen, must be justified with evidence to both the HSE and BEIS. The process for such significant changes is currently being progressed and developed as part of the HyDeploy project. As a primary partner to the project, the Health and Safety Executive Science Division (HSE-SD) have a direct link to the HSE, ensuring that open communication with this critical stakeholder is efficient and effective.

Section 8. Customer Impact

8.1 Customer commitment and understanding

All GB GDNs have a strong focus and commitment on care for their customers as evidenced by their established processes adopted as business as usual for minimising disruption when undertaking work on their networks.

83% of UK households are connected to the gas grid with their homes heated and hot water provided by natural gas via boilers. Alternative solutions for domestic customers such as heat pumps could require substantial disruption to customers for installation of the infrastructure required, as well as the appliances in the homes. In contrast, a GB gas distribution grid conversion to 100% hydrogen would decarbonise heat, whilst also causing minimal disruption in the homes and the highways when compared with alternatives.

It is important that customers are properly informed and engaged through the provision of timely, clear and visible information. This also provides an opportunity for the customer to understand the valuable role they will be playing in revolutionising how the UK could decarbonise its heating sector.

Drawing on Phase 1 of the Project and the social sciences research undertaken during this phase, an increased understanding of customers concerns about 100% hydrogen conversion was gained. Their concerns are particularly focused around the possible financial and disruptive elements of a possible conversion. As a result of this, Phase 2 will focus on understanding how to communicate effectively with customers so that they are equipped to make informed choices about their future energy supplies, rather than choices based on misunderstanding and misinformation that could unnecessarily disadvantage them. This aspect of the Project will require continuation of the robust stakeholder engagement and knowledge dissemination strategy employed during Phase 1 of the project, as outlined in Section 5. Knowledge Dissemination. As the main point of contact with customers living within our networks, we have a responsibility to ensure that customers are fully informed and equipped to make choices. To do this, Phase 2 will establish how to frame and communicate complex information in a way that empowers customers to make choices about their post-conversion energy source.

8.2 Customer Impact

The H21 Network Operation project has four phases which will each have different levels of impact on customers. No phase, however, will have any impact on customer's gas supplies. The specific type of customer impact per phase is summarised below with a detailed explanation thereafter.

- **Phase 2a – Appraisal of Network Operations.** Expand the test facility at Spadeadam to support the physical testing of all industry processes, procedures and operations. No customer impact in terms of charging, contract interruption or interaction with customer premises.
- **Phase 2b – Unoccupied Network Trials.** Network Operations on an unoccupied in-situ gas network. No impact on customer gas supplies; however, a pre-emptive customer engagement plan will be developed drawing on the learnings from the HyDeploy and HyDeploy$_2$ projects to ensure customers are aware of what works are being undertaken.
- **Phase 2c – Combined QRA.** Updating of QRA and coordinating QRA updates with H100 and Hy4Heat teams. No customer impact as outlined above.
- **Phase 2d – Social Sciences.** No impact on customer gas supplies; however, direct engagement with customers to answer the research questions posed in this phase of the project with regards to 100% hydrogen conversion.

8.2.1 *Phase 2a – Appraisal of Network Operations. Expand the test facility at Spadeadam to support the physical testing of all industry processes, procedures and operations*

This phase will be an extension of the existing WBS1 site, where the three properties and dispersion experiments are currently being conducted for H21 NIC Phase 1b. The development of this facility will accelerate industry engagement through workshops, conferences, meetings with industry professionals from around the world and publications in industry journals, magazines and the general media; as well as broaden the knowledge base of industry through direct trials and testing alongside scientific modelling. Testing during this phase will comprise of gas industry professionals identifying optimum operating techniques, proving new and established procedures and delivering outcome appraisal to capture the learning.

Due to the nature of these processes, procedures and operations, and the unknowns of performing these on 100% hydrogen the extension of the existing WBS 1 site (the DNV GL Spadeadam Research and Testing Centre) has been chosen as the location for Phase 2a – Appraisal of Network Operations. It is a secure, remote site with a comprehensive array of engineering and scientific equipment and facilities specifically designed for the planned testing activities, e.g. emergency procedures, planned procedures, maintenance of network assets and network validation and modelling among others.

DNV GL Spadeadam and Research Testing Centre has an established stakeholder and customer management processes which will be in operation during any testing. This includes liaison with the RAF staff for overall site control and local residents as part of the daily plans.

8.2.2 *Phase 2b – Unoccupied Network Trials. Network Operations on an unoccupied in-situ gas network*

Network Operations will involve tests on in-situ, existing, undisturbed gas mains and some above-ground assets. This phase will be undertaken on an unoccupied in-situ, undisturbed gas network, the purpose of which is to bring together the results of the leakage evidence gathered in H21 NIC Phase 1a with the learning developed from H21 NIC Phase 2a. These tests will not be undertaken on live mains or downstream of the ECV and therefore will not impact customers' gas supplies in any way.

The H21 NIA Field Trials project will continue to liaise extensively with local authorities, the MOD and private network sites to find a suitable location. The scope for this location is a derelict or demolished site with existing network assets that have been isolated from the network and do not impact end-use customers. Locating a site within these parameters will ensure no customer impact and a safe, but 'real-life' environment for carrying out network operations testing.

To date, several sites have been identified and are being assessed against the parameters of the scope mentioned above. Ultimately the site selected for Phase 2b – Unoccupied Network Trials will represent the best value for money in terms of cost, range of assets available, surrounding land use and level of customer impact. The selected site will be provided to the H21 Network Operations project under legal agreement between the site owners and the networks for the duration of Phase 2b – Unoccupied Network Trials.

Phase 2b – Unoccupied Network Trials will be carried out under a well-developed safety management system supported by the evidence from H21 NIC Phases 1a and 1b and H21 Network Operations Phase 2a – Appraisal of Network Operations. The stakeholder engagement and knowledge dissemination processes will be followed throughout this phase. Additionally, a customer engagement plan will be developed to ensure that customers in the surrounding area are fully aware of the work being undertaken. The customer engagement plan will draw upon the learnings from the HyDeploy and $HyDeploy_2$ customer engagements plans and will encompass local council meetings, MP surgeries and community centre meetings/drop ins. At present the unoccupied site is assumed to be located within a public area. However, it could be the case that the location is on MOD or private land; if this is the case the customer engagement plan will be developed to reflect this. The customer engagement plan will be approved by the

Steering Board and will identify how ongoing communications with our customers will be sustained, how safety related information will be communicated to customers, how customer queries and complaints will be handled and how customers data will be protected under the requirements of GDPR.

8.2.3 Phase 2c – Combined QRA. Updating of QRA and coordinating QRA updates with H100 and Hy4Heat teams

The H21 NIC project is updating the existing gas network Quantitative Risk Assessment (QRA) for transportation of hydrogen. Results from H21 Network Operations Phases 2a and 2b will be incorporated to develop this further, updating and refining the evidence feeding the QRA model. All QRA updates will be coordinated with the H100 and Hy4Heat teams.

No customer impact is expected on this phase of the project.

8.2.4 Phase 2d – Social Sciences. Research

Whilst there will be no direct impact to customers’ gas supplies, customer engagement will form a crucial part of this phase to understand the right communication messages and channels that should be used when the project progresses to stages with more direct customer impact e.g. roll out of the conversion process.

Leeds Beckett University will recruit participants who would like to take part in research projects. They can specify the demographics and locations of these participants so that they are representative of local communities, as well as those who fit the groups identified in Phase 1 of the research. Participants are paid industry-standard incentives.

The research will have approval from the University’s ethics board. This involves reviewing the aim of the research and its methods to make sure that the research will do no harm to those involved in the study (both participants and researchers); that participants can make an informed choice about taking part; that they are aware of how the research data will be used, stored and eventually destroyed; and that they know they can change their mind about taking part and how they go about doing so. The lead researchers are Chartered Health Psychologists and comply with the British Psychological Society Code of Ethics and Conduct. The ethics processes also assure GDPR compliance.

Section 9. Project Deliverables

Ref	Project Deliverable	Deadline	Evidence	NIC Funding Request
1	Network Operations Procedure Review	01/12/20	A series of detailed reports providing an assessment of the Basis of Safety (BoS) for hydrogen. Updated Master Test Plan (MTP).	11%
2	Building Phase 2a micro-grid	10/09/20	Construction of the extension of Spadeadam site completed as per design.	22%
3	Completion of Phase 2a testing	09/09/21	Tests identified in the MTP have been attempted and results documented in a technical note. Updated H21 QRA.	15%
4	Design of Phase 2b site	06/11/20	Approved detailed design for Phase 2b site.	3%
5	Pre-construction works for Phase 2b site	05/11/20	All legal and insurance contracts complete. Site set-up, gas supply and security complete. Pre-validation surveys complete including leakage surveys, internal CCTV surveys, trial excavations and pressure testing.	9%
6	Construction of Phase 2b site	28/01/21	Construction of control centre, measurement points and installation of any other assets as per the approved design.	20%
7	Testing of Network Operations for Phase 2b	07/10/21	MTP updated with technical notes from Phase 2b. Report on the initial identification of training gaps for operatives. Updated H21 QRA.	15%
8	Phase 2c Combined QRA	22/10/21	A combined QRA accepted by both Hy4Heat and H21.	3%
9	Phase 2d Social Sciences	29/04/21	A glossary of terms to be used in future communications. Results from online survey and statistical modelling of feedback for reaction of 100% hydrogen conversion. Educational communication materials.	2%
10	Comply with knowledge transfer requirements of the governance document	31/12/21	Annual Project Progress Report which complies with the requirements of the governance document. Completed Close Down Report which complies with the requirements of the governance document. Evidence of attendance and participation in the Annual Conference as described in the governance document.	N/A

Section 10. List of Appendices

Appendix	Title	Description
A	Benefits Tables	Benefits tables (2 Pages)
B	Benefits Justification	Detailed description of how the financial and environmental benefits were calculated. This section also provides much more detail in support of section 4. (7 Pages)
C	Gap Analysis	Detailed description of the knowledge gaps supporting our approach to Phase 2 (6 Pages)
D	Detailed Project Description	Detailed description of the project including all phases. (17 Pages)
E	Governance and Organogram	An overview of the contractual and project team structure. (2 Pages)
F	Gantt Chart	The programme of delivery for the project (2 Pages)
G	Risk Register	The risk register and mitigation strategies for the project (3 Pages)
H	Cost Breakdown	Overall costs for the project broken down by Project Management and delivery by phase. (1 Page)
I	Project Partners	A detailed overview of key partners and personnel who will be engaged on the project. (4 Pages)
J	Stakeholder Engagement to Date	A comprehensive list of stakeholder engagement undertaken. (4 Pages)
K	Letters of Support	Letters from (3 Pages): • ENA • HHIC, • Cadent Gas, • TVCA, • IGEM, • National Grid, • Project Rome, • Netbeheer Nederland, • AusNet Services, • Arup, • Energy Networks Australia • AGN • Leeds City Council
L	Signed NIC bid Acknowledgment Document	A document signed at Director level by all GB GDNs confirming their support and financial commitment to the H21 NIC bid. (2 Pages)

Appendix A. Benefits Table

Method	Method name
Method 1	Baseline scenario taken as option one from Section 11 of the H21 NOE report

<u>Gas NIC – financial benefits: Cumulative Financial Benefits (NPV terms; £m)</u>

Scale	Method	Method Cost	Base Case Cost	Notes			Cross-references	
				2030	2040	2050		
Post-trial solution *(individual deployment)*	Method 1	N/A	N/A	N/A	N/A	N/A	N/A	An incremental 100% hydrogen conversion of the GB gas distribution networks could only be undertaken with significant scale and a policy decision. The scenario presented in the H21 report could be considered a 'minimum' initial policy position i.e. $^{1}/_{3}$ of the gas network. The scale in the scenario is reasonable but initial urban centres converted could change from those suggested. For example, the 'Northern Power House' could be used instead of the major cities across the UK. With subsequent policy extending to other areas.
Licensee scale *If applicable, indicate the number of relevant sites on the Licensees' network.*	Method 1	N/A	N/A	N/A	N/A	N/A	*N/A*	
GB rollout scale *If applicable, indicate the number of relevant sites on the GB gas distribution network.*	Method 1	App B (B3)	App B (B3)	5,033	30,506	46,191	*circa $^{1}/_{3}$ gas conns*	*All assumptions in Appendix B (Section B3) summarised further in bid Section 3.3.1 & 4.1.4.*

Gas NIC – carbon and/or environmental benefits: Cumulative Carbon Benefits (tmCO2e)

Scale	Method	Method Cost	Base Case Cost	Notes			Cross-references	
				2030	2040	2050		
Post-trial solution *Leeds*	Method 1	N/A	N/A	1	11	21	N/A	An incremental 100% hydrogen conversion of the GB gas networks could only be undertaken with significant scale and a policy decision. The scenario presented in the H21 report could be considered a 'minimum' initial policy position i.e. $^{1}/_{3}$ of the gas network. The scale in the scenario is reasonable but initial urban centres converted could change from those suggested. For example, the 'Northern Power House' could be used instead of the major cities across the UK. With subsequent policy extending to other areas.
Licensee scale *North of England Scope*	Method 1	N/A	N/A	1	52.8	154.5	*N/A*	
GB rollout scale *If applicable, indicate the number of relevant sites on the GB gas distribution network.*	Method 1	App B (B3.2)	App B (B3.2)	1.0	55.3	241.8	*circa $^{1}/_{3}$ gas conns*	*All assumptions in Appendix B (Section B 3.2) summarised in bid Section 3.4 & 4.1.3*

Environmental benefits which cannot be expressed as tCO_{2eq}: The benefits have been calculated based on guaranteed CO_2 savings from heat alone. However, there would be significant benefits arising from the rapid uptake of hydrogen vehicles across cities with hydrogen gas distribution grids. These could be more significant than heat as hydrogen fuel cell vehicles not only remove carbon dioxide but also particulate matter and NOx. For the purpose of this H21 NIC bid trying to calculate this benefit was considered over complicated and held too much reliance on projected uptake of vehicles, however, the heat benefit savings are guaranteed.

Additionally, fugitive methane emissions (25 times more detrimental to the environment than CO_2) from natural gas distribution network leaks (current leaks) would no longer pose an environmental threat from hydrogen gas distribution grids. Finally, for hydrogen converted areas, carbon monoxide risk would be eliminated entirely as it is not possible to get carbon monoxide poisoning from a hydrogen appliance.

Appendix B. Justification of Financial and Carbon benefits

B.1. Strategic approach

The H21 North of England (NoE) NIA project issued in 2018, built on the H21 Leeds City Gate (LCG) project and assessed the feasibility of converting the gas distribution network for the North of England from natural gas to 100% hydrogen.

The Project was designed to be a blueprint study to prove that the gas distribution network of Great Britain could be converted to 100% hydrogen. Specifically, it confirmed:

- That the gas distribution network has sufficient capacity to convert to hydrogen, i.e. the pipes were big enough, with minimal upgrading.
- That a secure supply of zero carbon hydrogen could be provided to meet the annual and peak demands of the cities. This would be achieved via Autothermal Reforming (ATR) coupled with Carbon Capture and Storage (CCS).
- That intra-day (within day) and inter-seasonal storage could be managed alongside hydrogen production facilities (ATRs) using salt caverns developed in the salt deposits available across the UK and specifically in the North-East region.
- That the North of England could be converted incrementally with minimal disruption to customers. This would be undertaken in a similar fashion to the towns gas to natural gas conversion which occurred across the UK between 1966 and 1977.
- The overall costs for such a conversion and a recommendation for how that could be financed with minimal impact on customers' bills.
- How such a conversion could be undertaken incrementally across the UK over time, which would provide the single biggest contribution to decarbonisation.

All the technology identified and developed in the H21 NoE project can be evidenced across the world today. The project suggests that an incremental conversion (i.e. one city then the next) to 100% hydrogen within the UK gas distribution network is technically possible and economically viable.

Converting the gas distribution network to hydrogen would provide large-scale decarbonisation of heat with minimal disruption to existing customers versus alternative options. Alternative options can be considered to include electrification of heating, district heating and energy efficiency. Additionally, converting the gas distribution network to 100% hydrogen is an immediate and long term low carbon option as the system would provide a deep, system-based level of decarbonisation from the day of conversion. Electrical heating options and district heating are only low carbon if the electricity or heat is decarbonised at source. This would not be likely from day one and there are many uncertainties around how or if this could be technically, economically or socially achieved.

The H21 NoE report provided a detailed and robust analysis of the carbon savings associated with production of hydrogen via ATR, coupled with CCS. This was chosen as the most credible source of economic, large scale and low carbon hydrogen supply based on international evidence. Most of the world's hydrogen is produced using this proven technology. The largest ATR in operation is the Oryx gas-to-liquid plant in Qatar. The unit has been in operation since 2006 and produces 600,000 Nm^3/h of syngas equal to 2.1 GW of hydrogen.

A practical, incremental roll-out scenario for 100% hydrogen conversion across the UK was presented in Section 11 of the H21 NoE report. As the H21 NoE project represents the most advanced document to date on GB gas distribution network conversion to hydrogen, the figures from this report have been used to develop the carbon and cost benefits up to (and beyond) 2050.

B.2. Carbon and environmental benefits

B.2.1. *Baseline Scenario (Information based on Section 9 H21 NoE report)*

A significant advantage of a 100% hydrogen conversion is that roll out across the UK can be achieved incrementally at a rate dictated by appetite for cost and carbon reduction. To provide some clarity on what a roll-out strategy could look like, Section 4 of the H21 NoE report describes an example of incremental conversion, involving many major cities and major urban centres for the North of England, and Section 11 describes the roll out of the UK conversion covering around 30% of gas users. The example presented in the H21 LCG report (Option 1) provided significant carbon benefits in a relatively short time whilst ensuring broad UK coverage to encourage wider benefits (transportation/electrification).

The cities and major urban centres considered for conversion as part of this option include: Leeds (city), Teesside (greater area), Kingston upon Hull (city), Newcastle (greater area), Manchester (greater area), Sheffield (city), Liverpool (greater area), Edinburgh (city), Glasgow (greater area), Birmingham (greater area), Bristol (city), Cardiff (city), Aberdeen (city), Leicester (city), Luton (city), Oxford (city) and London (greater area). All other areas in this scenario could remain on a natural gas/biogas/hydrogen blended mix or be fully converted in the future.

When considering an incremental conversion to 100% hydrogen, there are many other advantages and environmental benefits that have not been factored into the analysis for the H21 NIC, due to adding unnecessary complexity. However, they have been included below for completeness and consideration:

- The existing high-pressure natural gas network will remain in place for large industrial users such as power stations. These industrial users can be converted onto the Hydrogen Transmission System (HTS) at the end of their asset life, providing low carbon decentralised electricity generation.
- Fuelling stations can be built adjacent to the city's hydrogen grid which would allow a greatly accelerated decarbonisation of transport alongside electric vehicles.
- Converting some of the UK cities' worst transport polluters to hydrogen (or initially natural gas) has a significant beneficial impact on air quality by removing NOx and particulate matter emissions from vehicles with no electrical alternative, for example garbage trucks.
- During or following conversion to 100% hydrogen, the uptake of micro-Combined Heat and Power (CHP) by homeowners could have a huge impact on decarbonisation of electricity. This is because generating electricity locally removes the current electrical system efficiency losses. This results in less requirement for central generation and no loss of energy due to transporting electricity down cables.

B.2.2. *Carbon Intensity*

The rationale for any natural gas to 100% hydrogen conversion must be a net reduction in emissions of carbon dioxide and other greenhouse gases, expressed as their carbon dioxide equivalent in line with the Kyoto Protocol, but quantifying this can be complex. When comparing the carbon emissions of any product or service it is vital to compare like with like, and to define the boundary conditions in a coherent fashion.

Commonly, carbon emissions are compared at three different levels and, for meaningful discussions, it is vital to agree the concepts behind these. Without this, society can make erroneous decisions. These three levels are:

Scope 1: These are the direct emissions within the system boundary of the end user and hydrogen production facilities (typically from a boiler or vehicle). For stationary plant they are usually evaluated at g/kWh of fuel. For natural gas they are typically 184 g CO_2e/kWh_{HHV} (Defra/DECC data set 2015). They usually make no allowance for the carbon dioxide emitted in (for example) liquefying the natural gas in Qatar, transporting it in refrigerated ships, storing it in LNG depots, re-gasifying it and compressing it into the national transmission system. For the H21 system these include emissions associated with the production of hydrogen and carbon at the ATRs.

Scope 2: Typically allows for Scope 1 carbon emissions and for additional energy inputs to the system such as electricity from the grid. For the H21 system these include the electrical consumption of the plant and the compression requirements (both CCS and hydrogen).

Scope 3: Endeavours to capture the embodied carbon emitted in material inputs to the system, for example LNG refrigeration and transport of product.

Establishing the CO_2 Emissions for H21 North of England

H21 LCG used the Defra/DECC natural gas emission figure of 184.45 g CO_2e/kWh_{HHV} (Defra/DECC data set 2015, Scope 1 emission) emitted directly from the combustion of natural gas and a further 24.83 g CO_2e/kWh_{HHV} (Defra/DECC data set 2015, Scope 3 emission) by the natural gas supply system making a total of 209.28 g/kWh for the present natural gas supply.

Further to the LCG report the NoE report further develop the CO_2 emissions with Equinor. Equinor also brought their experience of hydrogen production. This meant that the LCG proposed use of SMR for hydrogen production was changed to AutoThermal Reforming (ATR). The table below details the relevant parameters which directed this decision.

1.5 GW H_2 production	ATR Option 2	SMR Option 2
Carbon capture rate (%)	94.1	91.2
CO_2 footprint (g CO/kwh)	13.1	20.5
Efficiency % (HHV)	79.9	79.5
CAPEX (£m) Total	947	1,082
Electric power import (MW)	72.6	35.6
CAPEX £/kwh_{2HHV}	631	721
Area (ha)	15-20	35-40
Configuration	1 ATR train + ASU	2 SMR trains

Table 4: H21 NoE ATR vs. SMR emissions comparison

These factors were used to estimate what the emissions from the H21 NoE system were.

Scope 1 Emissions Associated with the Production of hydrogen and Carbon Dioxide at the ATR

The main emissions from the H21 system will come from the ATR plants which convert natural gas to hydrogen and capture approximately 94.1% of the carbon in the feedstock. The highest practical efficiency (HHV basis) of the ATR is 79.9%. The carbon footprint of produced hydrogen at an estimated carbon capture rate of 94.12% and efficiency of roughly 83.1%.

The carbon footprint of the ATR+CCS has been evaluated as follows: The carbon footprint of the natural gas feedstock = 184 g/kWh.

With no carbon capture capability and an efficiency of 74.4% = 247 g/kWh (184/0.774).

94% of the carbon dioxide will be captured by the CCS system, therefore the direct CO_2 emissions from this process are 14.40 g/kWh (Scope 1).

Scope of emissions	H21 NoE system based on 2018 UK mix (g/kWh)	Natural gas (g/kWh)	% reduction in emissions
Scope 1	14.40	183.6	92.2%
Scope 1+2	14.47 (14.4 + 0.073)	183.6	92.1%

Table 5: Scope of emissions table

Scope 2 Emissions Include the Electrical Consumption of the Plant and the Compression Requirements (both CCS and hydrogen)

The system utilises electric power to drive pumps and fans for the carbon capture process and the large compressors which send the captured CO_2 to storage. The ATR plant could, in principle, generate this power from the waste heat produced by the conversion process. However, this requires additional equipment and the simplest concept is to import this power from the UK electrical grid. This would result in an additional emission of 0.073 g/kWh (DEFRA emission factor 2015).

Total Scope 2 emissions are:

- Hydrogen/carbon production = 14.40 g/kWh. (scope 1)
- Electric requirements for ATR plant = 0.073 g/kWh
- Electrical hydrogen compression requirements = 0 g/kWh (not applicable with ATR as the hydrogen is produced at high pressure)

Total emissions = 14.47 g/kWh.

It is important to remember that this figure is based on the 2015 electricity grid carbon footprint, and sub optimised SMR+ATS performance to give a worst-case scenario. The final ATR+CCS design would give better capture and efficiency and the UK electric grid will continue to be decarbonised.

For this NIC bid the scope 2 emissions have been used to quantify the carbon benefits. Adding scope 3 emissions is contentious and potentially disproportionate, based on the varying supply of LNG to the UK and conservative Scope 2 figures mentioned above.

Total yearly volume of captured carbon

The amount of CO_2 sent to disposal during a year of operation for the H21 NoE system is 17.3 million tonnes per annum. The calculation can be seen in the table below:

	Unit	On site emissions
Natural gas	g/kWh	184
NoE design	TWh/yr	74.45
Current emissions CO_2	$MtCO_2$ eq/yr	13.7
H21 NoE CO_2 avoided	$MtCO_2$ eq/yr	12.6
ATR		
Conversion rate	%	74.7%
Natural gas to ATR	TWh/yr	99.7
Total CO_2 in natural gas	$MtCO_2$ eq/yr	18.3
CO_2 to CCS	%	94%
CO_2 to storage	$MtCO_2$ eq/yr	17.3
CO_2 to atmosphere	$MtCO_2$ eq/yr	1.1

B.2.3. *Project Volumes*

The projected volumes are based on the baseline scenario taken as option one from Section 11 of the H21 NoE report. The figures were calculated using the H21 NoE data and extrapolating this based on percentage populations for each major urban centre. For example:

Population covered in the H21 NoE figures = 22m

For the use of the table Leeds rounded to 1 $MtCO_2$ eq/year

The carbon savings are based on a proportional basis from Leeds

The H21 NoE report also gave an indication of timescales which may be considered reasonable for the conversion of the nominated cities.

The table below summarises the results:

City	Population guestimate (In area to convert millions)	Proportional variation from Leeds	Number of connections (customers)	Timeline		Carbon capture using proportional variation $MtCO_2$ eq year	Carbon capture per annum using proportional variation $MtCO_2$ eq
				Year start	Year finish		
Leeds	0.66	1.00	265,000	2026	2029	1.0	1.0
Teesside	0.56	0.85	225,250	2029	2032	0.9	1.9
Kingston Upon Hull	0.26	0.39	103,350	2029	2032	0.4	2.2
Newcastle	1.12	1.69	447,850	2032	2035	1.7	3.9
Manchester	2.41	3.65	967,250	2032	2035	3.7	7.6
Sheffield	0.56	0.85	225,250	2035	2038	0.9	8.4
Liverpool	1.71	2.59	686,350	2035	2038	2.6	11
Edinburgh	0.49	0.75	198,750	2036	2038	0.8	11.8
Glasgow	1.14	1.73	458,450	2039	2039	1.7	13.5
Birmingham	2.81	4.25	1,126,250	2039	2042	4.3	17.8
Bristol	0.44	0.67	177,550	2042	2042	0.7	18.4
Cardiff	0.35	0.54	143,100	2042	2045	0.5	19.0
Aberdeen	0.23	0.35	92,750	2042	2045	0.4	19.3
Leicester	0.34	0.51	135,150	2045	2045	0.5	19.8
Luton	0.21	0.32	84,800	2045	2048	0.3	20.1
Oxford	0.16	0.24	63,600	2045	2048	0.2	20.4
London	8.54	12.91	3,421,150	2045	2052	12.9	33.3
Totals	22	N/A	8,821,850	N/A	N/A	33.50	N/A

Table 6: H21 NoE report conversion timescales summary

To calculate the cumulative carbon savings from the hydrogen conversion presented in this scenario the annual captured carbon figures for each city have been projected up to 2050. This is summarised below:

City	Years to 2030	Total $MtCO_2$ eq saved to 2030	Years to 2040	Total $MtCO_2$ eq saved to 2040	Years to 2050	Total $MtCO_2$ eq saved to 2050
Leeds	1	1	11	11	21	21.0
Teesside	0	0	8	6.8	18	15.3
Kingston Upon Hull	0	0	8	3.1	18	7.0
Newcastle	0	0	5	8.5	15	25.4
Manchester	0	0	5	18.3	15	54.8
Sheffield	0	0	2	1.7	12	10.2
Liverpool	0	0	2	5.2	12	31.1
Edinburgh	0	0	1	0.8	11	8.3
Glasgow	0	0	0	0	8	13.8
Birmingham	0	0	0	0	8	34.0
Bristol	0	0	0	0	5	3.4
Cardiff	0	0	0	0	5	2.7

City	Years to 2030	Total $MtCO_2$ eq saved to 2030	Years to 2040	Total $MtCO_2$ eq saved to 2040	Years to 2050	Total $MtCO_2$ eq saved to 2050
Aberdeen	0	0	0	0	5	1.8
Leicester	0	0	0	0	2	1.0
Luton	0	0	0	0	2	0.6
Oxford	0	0	0	0	2	0.5
London	0	0	0	0	1/7th/year for 5 years	11.1
Totals				55.3		242

Table 7: H21 NoE report conversion carbon capture summary

The carbon benefits are summarised up to 2050 in the table below.

	To 2030	To 2040	To 2050
$MtCO_2$ eq saved	1.0	55.3	241.8

Table 8: Incremental carbon benefits summary to 2050

It is important to note that this scenario could be rapidly accelerated. The original towns gas to natural gas conversion converted the whole of Great Britain in 10 years which included 14 million customers (households) and 40 million appliances. The actual rate of conversion is dictated by the speed at which hydrogen production can be established.

B.3. Financial Benefits

The original H21 LCG study was based on the conversion of a comparatively small area when considered against H21 NoE. As with any large project, the associated cost savings which are realised through scale can be significant; this is the case with hydrogen conversion. The NoE is 13.3 times larger than LCG.

The KPMG report (p7 Executive Summary) provides an estimate of the differential cost to decarbonise heat between all-electric and hydrogen conversion options. These figures are summarised in the table below:

	Evolution of gas (predominantly 100% hydrogen networks)	Electric future	Mid-point scaling factor
Incremental cost per consumer up to 2050	£4,500-5,000	£12,000-14,000	2.74

Table 9: Estimated differential cost to decarbonise heat All Electric versus hydrogen

Using the 2.74 scaling factor, it is possible to work out a cost differential for customers to convert to an all-electric option versus 100% hydrogen conversion. This is summarised in the table below.

City	Population guestimate (millions)	Proportional variation from Leeds	Number of connections (customers)	Timeline		Cost per City Hydrogen (£Ms)	Cost per City Electric heating (£Ms)	Cumulative savings (£m)
				Year start	Year finish			
Leeds	0.66	1.00	265,000	2026	2029	1,896	5,189	3,923
Teesside	0.56	0.85	225,250	2029	2032	1,369	3,748	5,671
Kingston Upon Hull	0.26	0.39	103,350	2029	2032	604	1,653	6,720
Newcastle	1.12	1.69	447,850	2032	2035	2,778	7,602	11,545

City	Population guestimate (millions)	Proportional variation from Leeds	Number of connections (customers)	Timeline		Cost per City Hydrogen (£Ms)	Cost per City Electric heating (£Ms)	Cumulative savings (£m)
				Year start	Year finish			
Manchester	2.41	3.65	967,250	2032	2035	5,533	15,144	21,155
Sheffield	0.56	0.85	225,250	2035	2038	1,273	3,484	23,366
Liverpool	1.71	2.59	686,350	2035	2038	3,781	10,349	29,933
Edinburgh	0.49	0.75	198,750	2036	2038	1,386	3,793	32,340
Glasgow	1.14	1.73	458,450	2039	2042	2,579	7,059	36,820
Birmingham	2.81	4.25	1,126,250	2039	2042	6,012	16,454	47,263
Bristol	0.44	0.67	177,550	2042	2045	1,184	3,241	49,320
Cardiff	0.35	0.54	143,100	2042	2045	834	2,282	50,768
Aberdeen	0.23	0.35	92,750	2042	2045	849	2,322	52,542
Leicester	0.34	0.51	135,150	2045	2048	795	2,177	53,623
Luton	0.21	0.32	84,800	2045	2048	630	1,724	54,717
Oxford	0.16	0.24	63,600	2045	2048	515	1,410	55,612
London	8.54	12.91	3,421,150	2045	2052	17,007	46,545	85,150
Totals		N/A	8,821,850	N/A	N/A	49,026	134,176	85,150

Table 10: Cost differential for customers to convert to an all-electric option versus 100% hydrogen

The financial benefits are summarised up to 2050 in the table below.

	To 2030	To 2040	To 2050
Hydrogen conversion	£3,265m	£21,200m	£49,026m
All-Electric (using 2.74 scaling factor)	£8.937m	£58,020m	£134,175m
Costs avoided for customers versus All Electric	£5,671m	£36,220m	£85,150m
Savings to gas customers versus All Electric (NPV)	£5,033m	£30,506m	£46,191m

Table 11: Financial benefits summarised up to 2050

As with the calculated carbon benefits it is important to note that this scenario could be rapidly accelerated. The actual rate of conversion is dictated by the speed at which hydrogen production can be established.

Appendix C. Gap Analysis

C.1. Introduction

There have been significant advances in the research of the use of hydrogen as a suitable alternative to natural gas. Research projects have provided solid evidence this is achievable and have provided conclusions and recommendations from which further work is necessary to validate the overall goal of low-carbon energy supply through hydrogen.

Understanding how the projects interlink and what areas of investigations are being carried out shall ensure minimal duplication and deliver best value of money for customers. To date, H21 has carried out numerous collaborative exercises to ensure understanding of other project deliverables and prioritises the investigation of the gaps in knowledge which are not being explored by other projects. A high-level summary of these projects is shown in Table 1: Hydrogen project high level summary.

Programme	Appliances	Gas detection	Network Integrity	Operational Procedures	Customer acceptance
Blend					
HyDeploy	Re-use existing appliances	Work using existing detectors plus new CO sensor	Materials and leakage assessment for 1-year trial	Controlled site some local procedures changed	First demonstration of use 2018
$HyDeploy_2$	Re-use existing appliances	Develop approved new combined detectors	Network integrity assessment longer term	New procedures adopted on un-controlled site	First public demonstration of hydrogen use 2020
100% Hydrogen					
H21	n/a	Not in scope	Major programme to assess asset integrity and public safety	Major programme to assess network control on existing network	Element of social science research
H100	New appliances needed	Market appraisal and selection for trial	n/a	New PE related procedures adopted on new network	Engagement with host site
Hy4Heat	New appliances being developed	Downstream of ECV standards to be developed	n/a	New standards downstream of ECV to be developed	Engagement regarding home conversion

Table 12: Hydrogen projects high level summary

Through this collaborative approach, H21 have identified gaps in knowledge that still need to be explored in order to progress to occupied trials of the various hydrogen projects. One of these is the need to prove the suitability of the current gas network standard operation procedures, so that the trial sites can be operated and maintained safely.

Without the H21 programme, other hydrogen projects downstream of the Emergency Control Valve (ECV), e.g. Hy4Heat, will have gaps resulting in an incomplete body of evidence for 100% conversion. Therefore, it is imperative for H21 NIC Phase 2 project to be completed by the end 2021 in line with BEIS ambitions for live community trials.

C.2. Key objectives of Phase 1

The H21 NIC Phase 1 project provides quantified critical safety-based evidence towards proving that a 100% hydrogen GB gas distribution network represents a comparable and manageable risk to that of the natural gas network, with the aim of providing:

- The background leakage position of the network, i.e. does it leak more on 100% hydrogen and if so by how much and where?
- The consequences of hydrogen leakage both background and through network failures such as 3rd party damage, i.e. where does it go, and can it be ignited?
- The operational considerations for ongoing network maintenance, i.e. can leaks on the network be repaired safely.

Phase 1 centres around determining some of the fundamental parameters of hydrogen behaviours relevant to determining the comparative risk to natural gas. The methodology chosen was that of gap analysis of the existing natural gas QRA and designing experiments to provide knowledge to fill the gaps. This allows for model development and validation of predictions of physical behaviour.

Some limited operational demonstrations are scheduled in WBS5 but scoped to only include single demonstrations of certain techniques, (i.e. flow stopping techniques on both PE and metal mains, but only once and controlled remotely or, where this is not possible, with additional controls, for example specialised PPE).

The fundamental learnings from H21 NIC Phase 1 will provide information required for updating the phenomenological models for hydrogen but will not provide the large, statistically significant number of real operations required to validate some aspects of the newly updated models. Historically, the natural gas QRA models have been validated against the statistics for the numbers of incidents, gas in building events, explosions and fatalities gathered from the operation of a nationwide network.

Our analysis shows the following gaps in the holistic views of the full conversion to hydrogen:

C.3. Appraisal of Network Operational Procedures

The focus of the QRA study in Phase 1b is on the risks to the public from a 100% hydrogen gas network. Risks to workers undertaking activities on the network (including emergency repairs, planned replacement and maintenance) are not directly considered and are assumed to be controlled by safe working practices and procedures. One of the key objectives of Phase 2 is to gain experience of the conversion and operation of a natural gas network to 100% hydrogen network in a controlled environment, which will support the development of safe working practices and procedures for 100% hydrogen to control the risk to workers and members of the public.

Without this, further hydrogen projects cannot move to the field trial stage, as safe, proven and approved operational procedures will be required.

The H21 NIA Field Trials project includes a review and triage of the Network Operational procedures, which will provide a list, in the form of a Master Test Plan, of procedures that will require further investigation to prove suitability for use with hydrogen.

C.3.1. *Knowledge gap*

Information on the suitability of current methodology and procedures for network operations is required before operational activities can begin on other hydrogen related projects. H21 NIC Phase 1, whilst providing significant advances in knowledge, does not include procedural review and evaluation. The separate H21 NIA Field Trials funded project is being undertaken to review and triage the network operation and maintenance procedures to provide a Master Testing Plan. This does not include basis of safety, demonstration and testing of the procedures which is key to proving they are relevant and suitable for use with hydrogen.

Approach

- Review of procedures and establish the existing basis of procedural safety.
- Build a micro-grid and other suitable testing infrastructure
- Test and demonstrate procedures on the purpose-built gas micro-grid.
- Identify any gaps and specify work needed to fill these.
- Train and assess the competency of those operational personnel including managers and emergency response engineers identified to manage the remote conversion site in Phase 2b.

C.4. Network modelling

Natural gas network analysis models (most typically using a network analysis software package called Synergi owned by DNV GL) are validated on a regular basis against pressure data supplied by loggers on district governors (sources of gas) and network loggers (usually near the extremity of networks or adjacent to large demands). The models are also updated with demand information on an annual timescale. These processes ensure that the natural gas network analysis models closely reflect the reality situation for the networks. This is of extreme importance as these models are fundamental for the design of REPEX projects, reinforcement and diversion work and for both routine and non-routine work such as mains repair and district governor maintenance.

C.4.1. *Knowledge gap*

Whilst the modelling of a selection of distribution networks supplying 100% hydrogen has been carried out successfully (e.g. H21 NIA Strategic Modelling and subsequent validation of this by DNV GL) there is currently no real-world network involving a range of assets, flows and pressures to provide validation of these results. This is a fundamental gap that needs to be filled to provide the GDNs with confidence that the conversion strategies and reinforcement requirements identified in H21 NIA Strategic Modelling project (and going forward with the conversion) are valid.

Therefore, the construction of a micro-grid with the inclusion of several test areas in which to place assets of varying diameter and nature and then subject these to known flow volumes at a range of pressures is required. These test areas will give results for pressure drop and velocity which will be compared and validated against the values given by Synergi for the same conditions under natural gas.

Approach

- Model the pressure drop and velocities for 100% hydrogen across a suitable range of assets, demands and starting pressures to reflect those seen within the gas distribution networks.
- Validate these results against the behaviour observed on the gas micro-grid.

C.5. Hydrogen conversion method

The QRA study in H21 NIC Phase 1b is focussed on the risk to the public from the operation of a 100% hydrogen network. There will be safety risks (to both workers and the public) that could arise from the conversion process itself, which need to be considered and managed. This will also give an indication of the amount of time consumers will be impacted during conversion if current purging times or methods are required to change.

C.5.1. *Knowledge gap*

The risks associated with the conversion process are not part of the scope of H21 NIC Phase 1. The micro-grid and remote location trials will need to be converted to 100% hydrogen and so understanding and demonstrating the requirements to convert a network are needed.

Approach

- Undertake conversion of the micro-grid and the remote location site with hydrogen as part of the network operations testing which will assist in forming the initial research for the basis of the conversion process and safety evaluation.

C.6. Unoccupied Network Trials

The findings from H21 NIC Phase 1 and Phase 2a are based on testing equipment and procedures in a controlled environment that is not 100% representative of an existing in-situ network. The findings and conclusions from H21 NIC Phase 1 and Phase 2a must be validated and demonstrated in a remote unoccupied site demonstrating performance of an existing, in-situ, representative network in terms of operation, network leakage, detection and repair in the real world. The site will need to be representative of a typical small-scale network as it would be post 2032. Therefore, in consideration of the current Iron Mains Risk Reduction programme (IMRRP), the site will need to contain both PE and metallic assets and, ideally, existing pressure reduction equipment.

The Unoccupied Network Trials will provide confidence to the Duty Holders to move to community trials, ensuring a suitable and sufficient safety case can be submitted and agreed with the HSE. If the project doesn't undertake the unoccupied trials and there is an issue during the occupied trials, the Networks could be liable and face financial and reputational impacts as well as loss of credibility for, and public trust in the hydrogen conversion programme.

C.6.1. *Knowledge gap*

In order to progress with confidence onto a live community trial and, ultimately, conversion, a trial of conversion and operation of an existing natural gas distribution network under controlled conditions is imperative.

Approach

- Find a representative small-scale, in-situ network to convert to 100% hydrogen, by isolating from the existing natural gas distribution network (NIA Field Trials project).
- Validate the findings from H21 NIC Phase 1 and Phase 2a on an existing unoccupied site, demonstrating network operations in terms of network leakage, detection, and repair on a more representative network, validate model network flows and pressures on a larger scale network.
- Provide a platform to promote and demonstrate a hydrogen network in action.
- Identify the impact of the conversion process on customers, e.g. additional streetworks when installing conversion sector valves and the length of interruption to customer supply during the conversion process.

C.7. QRA

A comparative Quantitative Risk Assessment (QRA) is required which can be used to evaluate the difference in safety risk to the public associated with supplying 100% hydrogen versus natural gas. The risks calculated during H21 NIC Phase 1 cover the risk to the public from the network upstream of the ECV only, i.e. the network up to and including the ECV.

C.7.1. *Knowledge gap*

Historically, most gas explosion incidents are due to gas releases downstream of the ECV. The risks associated with the downstream pipework and appliances are being assessed separately, through the Hy4Heat programme supported by BEIS. To demonstrate that the combined risks to the public from 100% hydrogen gas distribution are acceptable, further work will be required to combine the contributions to risk from both upstream and downstream of the ECV (including the meter installation). Without this, it is not possible to make a full assessment of the safety-based evidence for 100% hydrogen conversion or to make a holistic comparison of the safety risks versus other zero-carbon alternatives.

Approach

- To review and combine the QRA from the Hy4Heat programme and the H21 programme into one QRA for 100% hydrogen conversion.

C.8. Social Sciences

Many other innovation projects are also looking into the Social Sciences aspects of conversion to hydrogen but as recognised by current research by Mandano[31] and The Institution of Engineering and Technology[32] support and acceptance of a gas distribution network conversion to 100% hydrogen will be crucial to its success. This research recognises that whilst the public understand and accept the importance of reducing carbon emissions, they have not recognised the implications of this with regards to decarbonised heat, and therefore heating their homes, in the future. Additionally, the research found that knowledge of low carbon heat technologies is relatively low, and that acceptability of these low carbon alternatives compared to current heating systems are viewed with scepticism when cost and disruption are factored into the public's consideration.

H21 NIC Phase 1 aims to generate insight into:

- Baseline public perceptions of the safety of hydrogen and other energy technologies/vectors.
- How people respond to the possibility of using 100% hydrogen for heating and cooking.
- How public perception of the safety of hydrogen evolves across the range of socio-demographic and geographic variables

C.8.1. *Knowledge gap*

So far, H21 NIC Phase 1 has identified that most people do not currently have a good understanding of, or interest in, how their energy is supplied. Our innovative approach – a Tier Definition Study involving members of the public – identified five different groups of people (Group 1: Acceptors – 20%, Group 2: Cautious – 28%, Group 3: Disinterested – 30%, Group 4: Concerned – 9%, Group 5: Rejectors – 12%) based on their potential reaction to a hydrogen conversion. Groups 2 and 3 were identified as critical markets for future communication.

It was identified that even in the most positive group, Acceptors, there was a lack of understanding of the terms that are used in the sector, such as decarbonisation, carbon capture and energy storage. The results from H21 NIC Phase 1 show the need to focus on several new objectives described below:

- Produce a glossary of terms that explain the key concepts underpinning a hydrogen conversion and the safety testing that has been completed. NGN can use this glossary across all its communication materials, such as websites, leaflets, letters, and scripts for door-to-door engagement officers. The terms will be suitable for both business and domestic customers. We will also produce an easy-read leaflet that explains a hydrogen conversion for people who have difficulties reading or understanding English.
- Produce an animation that explains the reasons for a hydrogen conversion and what it involves. This will provide an engaging and easy to understand account of what will happen and why. It therefore forms a valuable resource for customers who have difficulties reading English. It could be readily translated into several languages.
- Develop a beach-to-meter display that will be used at community engagement events to aid explanations of how hydrogen is stored and transported, and the practicalities of how the conversion is achieved.

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[31] Williams, H., Lohmann, T., Foster, S., Morrell, G. (2018). Public acceptability of the use of hydrogen for heating and cooking in the home. Mandano.

[32] The Institution of Engineering and Technology. (2019). Transitioning to Hydrogen: Assessing the Engineering Risks and Uncertainties.

With these in mind, the following approach in Phase 2 shall be taken;

Approach

- Co-production workshops- Workshops will be held with new groups of the public, joined by hydrogen professionals. Together they will co-produce materials that explain the issues and answer the questions that people have. We will hold six different workshops in three different locations, each attended by different members of the public. The first three workshops will identify the terms that need to be explained and will develop draft explanations of these terms. The second three – attended by different members of the public – will further develop the drafts into short, easy-to-understand definitions and identify any infographics that will aid understanding and acceptance.
- Storyboard groups- We will hold three focus groups to iteratively co-design an animation that explains a 100% hydrogen conversion in an accessible and engaging way.
- Display groups- Over the course of the three focus groups in three different locations we will iteratively co-design a prototype display that will help the public to understand how hydrogen is stored and transported, and the practicalities of how the conversion will be achieved in their area.
- Online survey- We will conduct an online survey with a representative sample of the UK population, with a target of 1000 respondents. The survey provides two functions: a randomised controlled trial of the effectiveness of the animation; and a statistical model to identify the importance of price, appliance cost, safety, disruption and sustainability in reaction to a 100% hydrogen conversion. The survey will also identify any socio-demographic groups who find the explanations more difficult to understand, and so will assist NGN's engagement team when communicating with different groups of customers.

Appendix D. Project Technical Description

D.1. Background and Purpose

The UK was legally bound to make ambitious carbon reductions under the terms of the Climate Change Act (2008). However, the UK Government signed legislation on 27th June 2019 committing the UK to a legally binding target of Net Zero emissions by 2050[33]. This means the UK must tackle decarbonisation at pace and change the way energy is produced, transported and consumed to meet this new target.

In 2017, 48%[2] of the UK's electricity was supplied by fossil-fuelled power generation (41% natural gas, 7% coal) with natural gas dominating the heat supply curve, heating 83% of buildings and providing most industrial heat. Heat demand is highly variable and, compared with alternatives, natural gas is readily capable of meeting peak heat demand. Therefore, there is a huge focus on finding a green alternative to natural gas.

Part of the solution is hydrogen. The Committee of Climate Change (CCC)[34] details that flexible power generation will continue to be required and will need to be decarbonised, probably via Carbon Capture and Storage (CCS) and hydrogen.

Hydrogen can be used as a low-carbon fuel for domestic and industrial heat, transport (including shipping) and power sectors. Producing hydrogen can be achieved with low emissions, by the development of advanced methane reformation facilities with CCS.

This brings further obstacles to overcome the need to distribute hydrogen around the country to where it is needed for the heat, transport and power sectors. Transporting hydrogen through the existing gas network must be an obvious solution to overcome this problem.

H21 is the only project in the UK currently looking at the possibility of converting the existing metallic and PE gas distribution network system 'upstream of the Emergency Control Valve (ECV)' to 100% hydrogen with the first phases examining whether the gas system will be able to carry hydrogen safely thereby providing low carbon fuel to homes and power generators in the UK. This will robustly contribute to decarbonising heat and power energy in the UK.

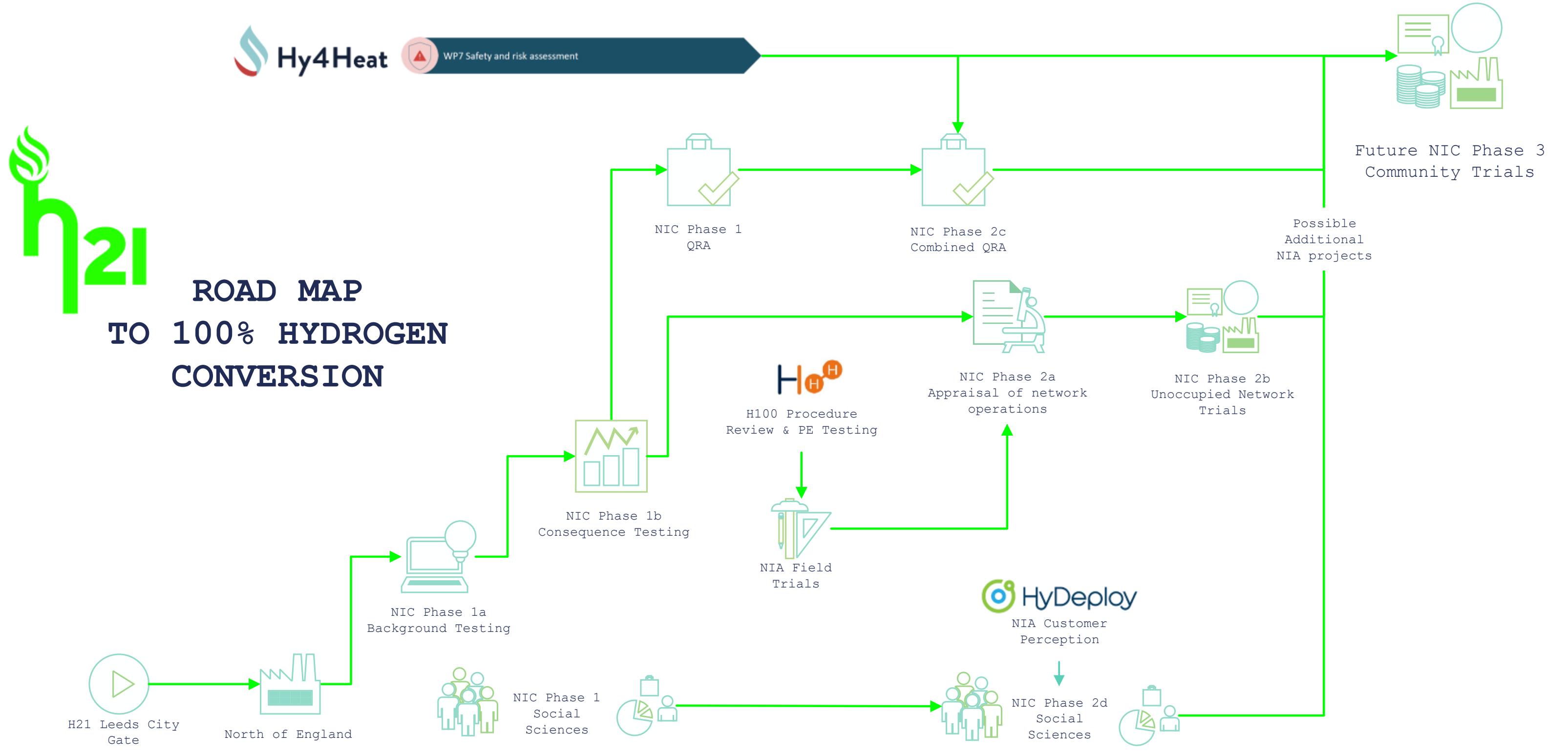
D.2. Project Approach

The aim of the H21 Programme is to provide safety critical evidence to support the viability of converting the UK gas distribution networks to 100% hydrogen. It builds on the work of the 2016 H21 Leeds City Gate (LCG) project and the 2018 North of England (NoE) project, both establishing hydrogen conversion as technically possible and economically viable. The H21 suite of projects will provide essential evidence to partner the Government's £25 million 'downstream of the ECV' hydrogen programme (Hy4Heat), which examines using hydrogen as a potential heat source in the home.

The objective of the H21 programme is to reach the point whereby it is feasible to convert the existing natural gas network to 100% hydrogen and thus providing a contribution to decarbonising GBs heat and power sectors with the focus on finding a green alternative to natural gas.

33 BEIS News Story - UK becomes first major economy to pass net zero emissions law
34 Committee on Climate Change, 'Net Zero – Technical Report', May 2019

The route to 100% hydrogen Conversion is depicted by the below Road Map with previous stages summarised in the following sections;



Confidence Gained	Conversion on scale is feasible	1a:Testing of real assets for gas tightness on H_2. 1b:QRA demonstrating relative risk of distributing natural gas compared with H_2 and identification of major risk contributors.	2a:Evidencing of procedures which continue to be suitable for hydrogen and confirmation of existing asset and model suitability. 2b:Demonstrating performance in terms of network leakage, detection and repair on a more representative network. 2c:Combined and overall view of risk of H_2. 2d:Postive customer perception.	It is feasible to covert the existing natural gas network to 100% hydrogen
Lay Summary	'focus on Safety & feasibility of reusing existing assets' 'Can you get enough energy to the customer without wholescale reinforcement'	'Is the network too leaky with H_2' 'What is the relative risk compared with natural gas'	'can you manage the network safely' 'validate network operations on an existing network' 'develop an overall view on risk with H' 'publicise and demonstrate a hydrogen network in action	'combining upstream/ downstream work to date' 'demonstrating occupied live trials of H2 conversion and management'
Stage	**Feasibility**	**Phase 1**	**Phase 2**	Phase 3

D.2.1. *H21 Work to Date*

NIC Phase 1: The H21 NIC Phase 1 project provides quantified critical safety-based evidence towards proving that a 100% hydrogen GB gas distribution network represents a comparable and manageable risk to that of the natural gas network with the aim of providing:

- The background leakage position of the network, i.e. does it leak more on 100% hydrogen and if so by how much and where?
- The consequences of hydrogen leakage, both background and through network failures such as third-party damage, i.e. where does it go, and can it be ignited?
- The operational considerations for ongoing network maintenance, i.e. can leaks on the network be repaired safely?

By 2032 approximately 90% of the GB gas distribution network will be polyethylene (PE). There will be some retained iron and steel mains along with a range of different PE pipe ages, various transition fittings, services, service connections, buried valves, repairs, service governors and district governors. Phase 1 aims to provide the quantitative safety-based evidence across a strategically selected range of these assets through a comprehensive two-phase testing programme as outlined below.

Phase 1a – Background testing: A strategic set of tests are being designed to cover the range of assets and pipe configurations representative across the UK. These tests will provide the quantitative evidence for changes to background leakage levels in a 100% hydrogen network.

Phase 1b – Consequence testing: Quantification of risk associated with background leakage as determined in Phase 1a. A QRA tool has been developed including linked mathematical models, which combine operational experience of the frequency and nature of uncontrolled gas releases with a linked series of mathematical models to predict the potential consequences (fire and explosion) in different circumstances.

Social Sciences: Phase 1 results show that we can currently segment the public into five groups based on their reaction to a potential 100% hydrogen conversion: Group 1, Acceptors (20%); Group 2, Cautious (28%); Group 3, Disinterested (30%); Group 4, Concerned (9%); Group 5, Rejectors (12%). Groups 2 and 3 were identified as critical markets for future communication as misperceptions or misinformation could move this large proportion of the public to reject hydrogen as a domestic fuel. We found that safety is not a major concern for most people (with the exception of Group 5). Most people accept that if their supply is converted to hydrogen then it will have been robustly tested and shown to be safe. Instead, people have concerns about the increased cost of gas and of purchasing new appliances and about the potential disruption arising from a conversion. Some were sceptical about the contribution to net zero that their domestic heating could make, as well as the overall contribution to global carbon emissions that the UK makes. We found that it is important to help people to understand key concepts such as carbon capture and storage, and to explain the current uncertainties over the timescale of a conversion, and the balance between blue and green hydrogen.

H21 NIA Field Trials: In parallel with Phase 1 the H21 NIA Field Trials project is carrying out a desk-based review of the key gas industry procedures for operating and maintaining the network to enable the development of an outline Master Test Plan (MTP). The outputs from this work will be used to focus the effort into the H21 NIC Phase 2, providing the design for the micro-grid to enable prompt commencement of the build of Phase 2a – Appraisal of Network Operations and preparation for Phase 2b – Unoccupied Network Trials.

Designers completed the conceptual design for the micro-grid in May 2019 and have now progressed to full detailed design. This has been a collaborative process with input from all other project partners including specific requirements such as flow simulation and measurement, and flexibility to simulate the entire range of operations currently undertaken on natural gas network.

The H21 suite of projects continue to work collaboratively with all project partners including HSE-SD, DNV GL and the other GB GDNs and NG through a series of workshops to define the required scope of the MTP.

The search continues to find a suitable unoccupied section of the GB network for the preparation for Phase 2b – Unoccupied Network Trials. The search area was originally confined to the NGN region but due to the lack of availability of suitable sites within Yorkshire and the North East, a nationwide search is underway where there is confidence a suitable location can be found. In the event that a suitable site cannot be found the project could utilise existing NGN operational pressure control sites that have decommissioned buried assets, utilise the HSE Buxton third party downstream buried gas network assets and retrieve assets from the networks and transport to Spadeadam to include on the mini grid.

D.2.2. *Key rationale for H21 NIC Phase 2*

It's vital: From source, hydrogen will need to get to the end user through the existing gas distribution network. It is known that hydrogen and natural gas are different in properties and behaviours and therefore the basis of safety needs to be reviewed and determined first. This is the only project looking at 100% hydrogen being transported through the existing network and safety evidence-based testing and modelling is the starting point to ensure customer and operator safety when using hydrogen in the existing gas distribution network system.

Conversion requires phased testing of assets: A tiered approach to the rigorous testing of existing assets and then the network as a whole is needed to demonstrate a basis of safety by modelling and testing hydrogen and natural gas on the same assets before controlled simulated trials and real-life network unoccupied trials, eventually leading to community trials with the integration of other projects such as Hy4Heat and H100.

End to end risk view paramount: By linking the upstream and downstream QRAs, for the first time the UK shall have a critical overall view of the risk of end to end 100% hydrogen conversion.

Positive customer perception is key: Ensuring the public understand what hydrogen conversion would mean for them during the process and seeing the long-term benefits in securing flexible low carbon heat/power energy for the future is paramount. This is a continual process from day 1 through to post conversion needed by all projects and the government, both to ensure that customers are empowered to make informed choices about their energy supply and that there are no delays to the hydrogen conversion process caused by unwarranted customer concerns.

D.2.3. *The Objectives of H21 NIC Phase 2*

The key objectives of H21 NIC Phase 2 are to further develop the evidence base supporting conversion of the gas network to 100% hydrogen.

The key principles of H21 NIC Phase 2 shall be to;

- Confirm how we can manage the network safely through an appraisal of network components, procedures, network modelling and testing.
- Validate network operations on an existing unoccupied network and provide a platform to promote and demonstrate a hydrogen network in action through remote location testing.
- Develop an overall view of the risk of 100% hydrogen conversion by linking the H21 QRA with the Hy4Heat 'downstream of ECV' QRA.

Establish how to frame and communicate complex information about a 100% hydrogen conversion in a way that best enables customers to understand and use it, and that avoids causing unwarranted confusion or negativity. This H21 NIC Phase 2 project will provide confidence in the network operations to be able move towards occupied trials, keeping pace with the Hy4Heat project and effectively determine **'can we manage the network and the conversion process safely'.**

The H21 project teams have been and will continue to liaise closely with other innovation projects including Hy4Heat and SGN H100, looking at 100% hydrogen conversion to ensure knowledge gaps in the holistic process are identified and that there is no unnecessary duplication of work.

This programme will be split into four primary phases which are described in more detail below:

- Phase 2a – Appraisal of Network Operations
- Phase 2b – Unoccupied Network Trials
- Phase 2c – Combined QRA
- Phase 2d – Social Sciences

D.3. Phase 2a – Appraisal of Network Operations

Summary: In order to carry out demonstrations on an unknown entity, a Basis of Safety (BoS) must be identified and development of safety and operational procedures must be completed as part of the enabling works. An assessment of the procedures/components that currently underpin all operations across the distribution network is needed to understand how to manage operational safety during and after the conversion.

The SGN H100 innovation project and the H21 NIA Field Trials project has initiated this, undertaking a triage review of the existing network operations procedures to determine the procedures that may be affected by 100% hydrogen. Where procedures are likely affected by hydrogen, then further investigation into the BoS and further testing of the procedures will be undertaken in H21 NIC Phase 2a and Phase 2b.

The outcome of this triage review will assist the development of the MTP, and further work may be needed later.

The MTP shall be developed alongside the detailed design of the micro-grid for network operation trials. This would ensure there is a simulated representation of a demonstration network to accommodate full scale network parameters and typical network components to run with 100% hydrogen or 100% natural gas.

Once built, the micro-grid test facility at Spadeadam would carry out all necessary tests as defined in the MTP to validate the network operation procedures and demonstrate the networks capability and suitability for hydrogen conversion. The data from these trials shall provide safety-based evidence that can be fed into the QRA to provide an updated picture of risk for network suitability.

Once expanded, as a simulated hydrogen network Spadeadam could be used to train operatives for Phase 2b – Unoccupied Network Trials. The controlled nature of the site is suitable for training operatives and could therefore be used in the future as a training facility if required by the GDNs and NG.

There are several key objectives for Phase 2a – Appraisal of Network Operations which are defined below;

i. To assess GDN procedures and identify those that should be suitable for a 100% hydrogen network and those where further work will be required.
ii. To build a gas demonstration network to accommodate full-scale network parameters and typical network components and run with 100% hydrogen or 100% natural gas.
iii. To demonstrate procedures identified in (i) on the purpose-built gas demonstration network.
iv. To test available hydrogen network models for validation against pressures and flows on the gas demonstration network and identify any further work required on these.
v. To review and update the QRA if required, with new information as it becomes available including results from Phase 2a

Below is a detailed technical description of how these objectives shall be met.

Methodology

D.3.1. *Phase 2a(i) Review of procedures*

Existing network procedures for the utilisation of natural gas and Liquefied Petroleum Gas (LPG) have evolved over many years and have benefited from those years of experience through primary evidence of incidents and near misses. This experience is incorporated in Industry Standards. This experience is lacking when considering hydrogen; therefore, more detailed scientific knowledge and demonstration will be needed to underpin any new standards.

The methodology for technically appraising network procedures follows several steps each designed to refine or evaluate the procedures or components used within the distribution network. The purpose of the exercise is to be able to understand what the current basis of safety is for a procedure/component, how it will change with 100% hydrogen and what evidence there is to support this. The evidence is crucial for two reasons; it will map out how safety can be managed in a network conversion and it will enable the proof of concept for an unoccupied field trial to take place.

The Phase 2a and Phase 2b trials will serve as a demonstration of the procedures, as well as contribute towards customer acceptance. The refining steps within the methodology are necessary as there is a large volume of procedures and components which manage the operation of the distribution network. Initially the list will be triaged to generate a shortlist of key procedures and components which will go on to be evaluated in more depth a detail.

The methodology will be applied to both procedures and components. Procedures will be used to exemplify the methodology in the steps below, but the process will be applied to both procedures and components to assess and evidence their suitability. Any deviations in approach from the steps for component specific details will be highlighted.

Pre-works NIA: The H21 NIA Field Trials project was initiated to provide valuable initial research on the status of operational procedures to enable the H21 NIC Phase 2 project to 'hit the ground running'. This will include;

- Identification of all relevant procedures/components that underpin operations of the distribution network, building on the works carried out by the SGN H100 project.
- Carry out a procedure/component review, sift and refine to generate a shortlist.
- Assess the current BoS for procedures and components.
- Evaluate for the possible effect of hydrogen on the BoS for procedures and components.

H21 NIC Phase 2 will further develop the NIAs work starting with:

Evaluating available evidence for hypotheses: This step is the cornerstone of the project and is where multiple sources of information will be collated to form a robust evidence base which underpins the safe operation of the distribution network for the conversion to 100% hydrogen.

It will be achieved by combining information from literature, modelling, experimental work and demonstration into a single narrative on the BoS for use with 100% hydrogen. The work in this step will identify procedures which need their BoS to be demonstrated by gathering evidence. A mixture of methods will be employed to gather appropriate evidence for such procedures. Testing and demonstration work will be undertaken on the DNV GL gas micro-grid as described in Phase 2a(iii) Demonstrate procedures on purpose-built gas micro-grid. The test programme will focus on where new BoS needs to be demonstrated and is difficult to evidence through literature, laboratory-scale testing, modelling and theory.

In addition to a review of the technical effects of converting to hydrogen, human factors specialists will also be involved in the review to consider the effects that humans have on procedures and how this might affect the BoS.

The outputs from this stage will be a catalogue of detailed reports that cover the main technical areas. These reports will bring together all the evidence in order to provide confidence in the assessment of the BoS. During this step, the procedures will be split into two groups based on the evidence available; those where there is a good level of justification for continued use and those where there is a weak justification for continued use and further work is needed to fill knowledge gaps. The MTP will be refined considering information gathered in this step.

D.3.2. *Phase 2a(ii) Build a micro-grid for demonstration and testing of procedures*

In order to complete the flow modelling, equipment performance testing and procedure validation, the test site in Spadeadam must be expanded to provide an experimental demonstration network.

As discussed previously, as part of the H21 Field Trials NIA designers have completed the conceptual design for the micro-grid in May 2019 and have progressed to full detailed design. This has been a collaborative process with input from all other project partners including specific requirements such as flow simulation and measurement, and flexibility to simulate the entire range of operations currently undertaken on the natural gas network. The detailed design shall be developed alongside the outline MTP to ensure that what is built suits the required flow assurance, equipment appraisal and the ongoing operation and maintenance of the network after conversion.

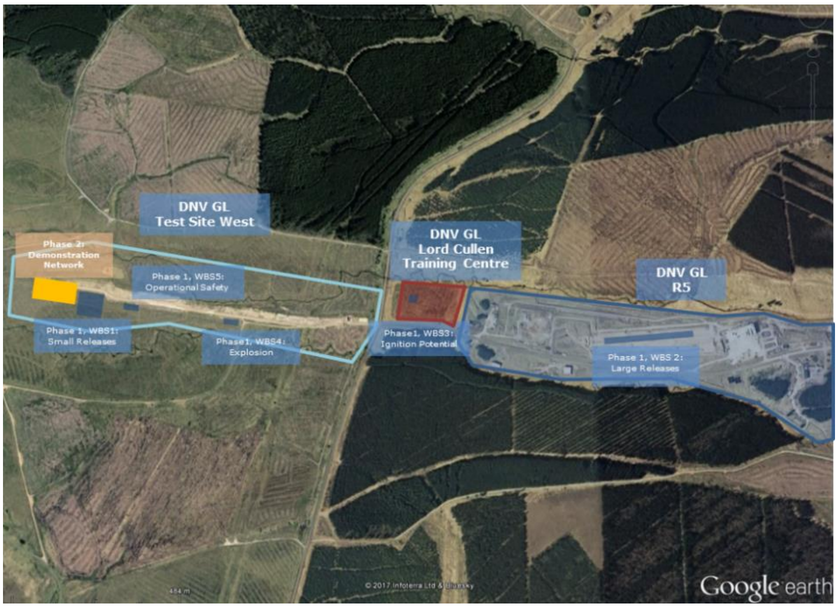
In conjunction with GB GDN representatives, a set of binding key operating parameters for the GB gas distribution network will be established. These parameters will be guided by current and historical network statistics for demand, supply pressures and knowledge of the make-up of the gas distribution network in terms of pipe sizes and proportionate lengths.

Some engineering judgement and evidence from H21 NIC Phase 1 and other hydrogen projects will be used to include additional parameters relevant to the operation of a hydrogen network, (e.g. pipe velocities will be higher for hydrogen than natural gas for the same representative energy content). These key parameters; flow rates, line pressures, and material/length/diameter combinations will form a design baseline for a bespoke micro-grid design. This micro-grid will be built to investigate safe conduct of operations and procedures identified in Phase 2a(i) Review of procedures.

The demonstration network will be further used to validate flow modelling techniques and to demonstrate conversion processes from natural gas to hydrogen through complex pipework. The demonstration flow loop will be built as an extension of the existing facilities constructed for Phase 1 at DNV GL's Spadeadam Research and Testing Centre.

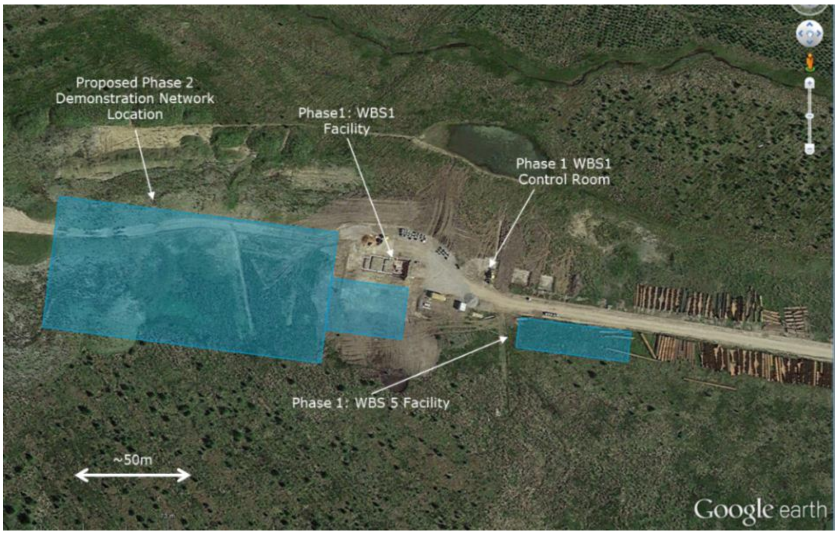
The site has been chosen to draw maximum value from the infrastructure investments already made from Phase 1 and to allow a demonstration network to be built within the confines of a site already conducting similar types of research as business-as-usual. The network can be built and operated under site-specific guidelines and procedures, greatly reducing the time-to-start associated with a stand-alone site. Spadeadam sits within a secure Ministry of Defence (MoD) site boundary with two-stage security access to the site, managed by the MoD and DNV GL.

Choosing Spadeadam has the benefits of infrastructure re-use, procedural efficiency and security but also means that trials of operations can be conducted away from the public eye in circumstances entirely within the control of the test site. The site has a history of building and operating large flow systems for both high- and low-pressure systems for example the GRAID[35] Project. Within the site boundary, the demonstration network will be sited in an undeveloped area immediately adjacent to the Phase 1 WBS1 facility



already in place. An ongoing, iterative design exercise is underway and will continue alongside the Phase 2a(i) activities to define a set of characteristics for the network to be able to satisfy the required operational trials and flow modelling validation. Final design of the network will involve input from DNV GL, HSE-SD and the GB GDNs with fixed infrastructure being prioritised to allow construction works to begin prior to finalised procedural review and programme development.

The demonstration network will include all the required elements of the distribution network:

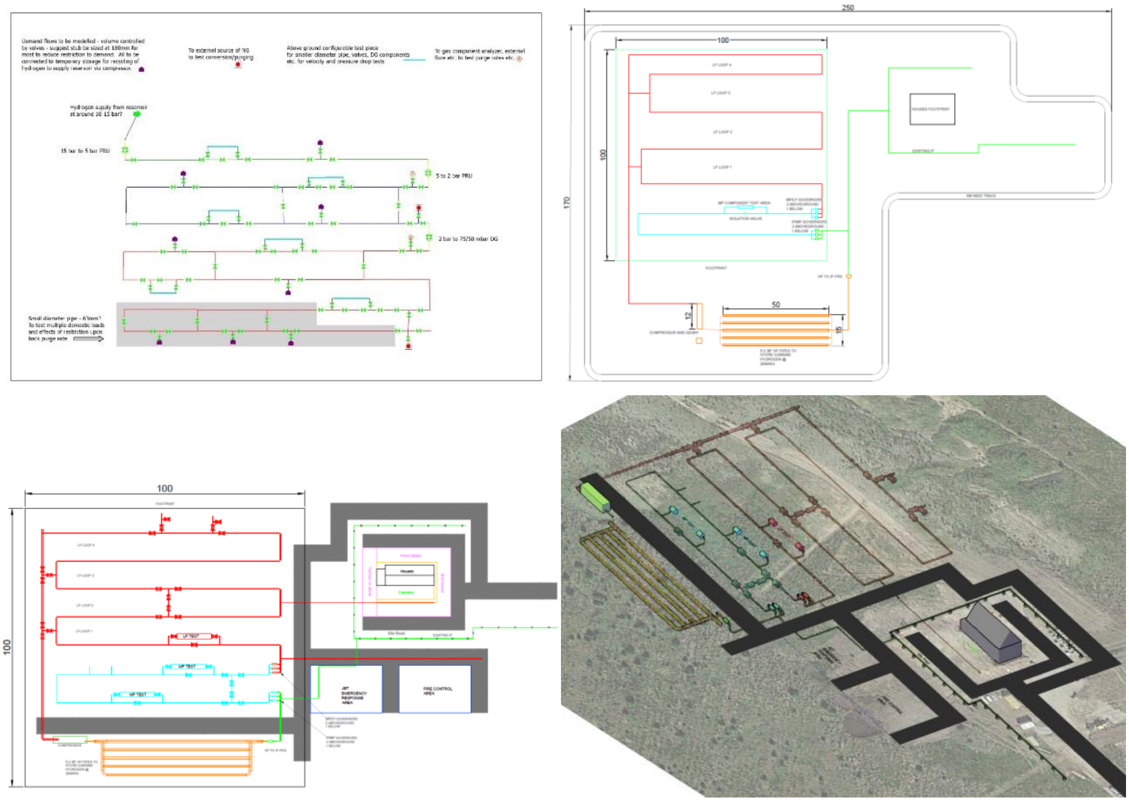


- Wide range of pipe sizes and lengths.
- All pressure ranges for distribution.
- Valves, dead-legs and loops for purging demonstrations.
- Interchangeable sections for installation of real network asset.

Additional infrastructure will include a high pressure hydrogen store (pipe array), access roads, and monitoring instrumentation. The current design utilises gas compression to re-cycle hydrogen in the demonstration network from low pressure back to high pressure – which will reduce testing costs by lowering the amount of hydrogen vented or flared to create load on the network.

As part of the build process, a set of baseline operating procedures for the demonstration network will be produced and peer reviewed at the site. The procedures will cover the basic operation of the network in terms of purging, pressurisation, venting (or flaring), flow generation and recompression. The facility will be assigned a maintenance schedule and Written Scheme of Examination as a permanent facility on the DNV GL Spadeadam Testing and Research Centre site.

[35] Project GRAID



Example drawings of the micro-grid

D.3.3. *Phase 2a(iii) Demonstrate procedures on purpose-built gas micro-grid*

On completion of Phase 2a(i) Review of procedures, the micro-grid will be utilised to perform demonstrations and experiments in a controlled environment. These activities will be supervised and supported by test site personnel alongside GDN's and their suppliers (e.g. component manufacturers).

As part of Phase 2a(i) outputs, procedures requiring further information and demonstrations of safe operation will be identified. All these demonstration activities will be performed to test protocols developed specifically to satisfy the needs of the demonstration on the micro-grid.

Some of these procedures will require further evidence for safety or operational/efficiency reasons. Where safety information is in doubt, these protocols will take advantage of the test environment and will include enhanced mitigation (e.g. remote actuation of equipment). The protocols will include guidance on the number of cycles / repetitions to perform on a given procedure to give a specific level of confidence.

In addition to the demonstration of procedures, the micro-grid will be utilised to simulate specific flow regimes in networks for the purposes of verification and validation of existing modelling techniques. It is necessary to understand the flow behaviour of hydrogen through networks and whilst there are network modelling tools capable of predicting this currently no relevant information exists for validation of the modelling tool results. Significantly, pressure profiles within the network must be predictable for comprehensive application of the QRA study to the expected hydrogen network of the future. Current knowledge suggests that the network models are entirely capable of modelling hydrogen flows, but verification is essential.

Prior to conducting conversion exercises during Phase 2b – Unoccupied Network Trials, the demonstration network will be utilised to investigate the practicalities and safety relevant aspects of converting from natural gas to hydrogen on a non-simple piping system. Information required will be associated with the practicality and safety of direct natural gas to hydrogen purge, e.g. required flow velocities, procedures for dead legs, services, purging and re-light procedures.

Several demonstrations would be undertaken by reusing some of the existing H21 NIC Phase 1b test facility where different materials, diameters, etc. can be swapped in and out to test various excavation, flow stop/connection techniques.

During the demonstrations on the network micro-grid, the operational procedures shall be continually monitored for compliance, the results of which will give a confidence level in the suitability of the procedures for future use. There are two possible routes to continue with this work based on outputs and level of evidence found in procedure reviews hypotheses identified in **Phase 2a(i).**

i. A good level of evidence is found from literature, theory, available data, results from experimental studies or validated models. The hypothesis about how the BoS will change with hydrogen is well understood and evidenced. In this scenario there will be a limited number of proof of concept-controlled experiments needed to demonstrate the theory at Spadeadam.
ii. A poor level of evidence is found to support the hypothesis. An idea about how the BoS will change with hydrogen will be made but there will be little available to evidence it. An extensive experimental programme may then be needed to provide assurance (both at Spadeadam and potentially outside of the programme), with a greater number of repeat tests generating detailed data.

During this stage, a decision will also be made about the first steps that would need to be carried out to enable the controlled unoccupied trial to take place. It may be that where there is a poor level of evidence available some form of work-around for these procedures may need to be considered (such as turning the gas supply off for some more sensitive operations). This would still enable the unoccupied trial to take place and build the required confidence, whilst in parallel a more enduring position on these procedures could be established.

It is crucial at this stage that all assumptions made as part of the assessment are documented to enable future users (collaborative partners) of the information to easily understand what can be drawn across to a wider suite of procedures (e.g. for higher pressure tiers) at a later date. With this in mind, a technical note for all procedures on the shortlist shall be recorded detailing:

- name of procedure
- purpose of procedure and operations it manages
- current BoS of procedure
- hypothesis about how BoS may change with hydrogen operations
- summary of available evidence to support hypothesis with reference to catalogue of technical reports
- decision about level of evidence available
- note of any known evidence gaps

Any evidence gaps that cannot be addressed within this NIC project will then be passed onto stakeholders/supply chain for further discussion and development.

D.3.4. *Phase 2a(iv) Establish hydrogen network modelling capabilities*

The modelling of the conversion of the GB gas networks from natural gas to hydrogen has been carried out within the Strategic Modelling NIA involving all the UK GDNs. This modelling process has been validated by DNV GL who are the owners of the modelling software used (Synergi). However, while the modelling of natural gas networks is validated and confirmed as reflecting the reality position within the gas networks on a regular basis by comparison with pressure loggers on both district governors and within the network, (e.g. extremity locations), there is no way to validate the pressures being forecast by the equivalent hydrogen models in similar fashion until after conversion.

Therefore, there is a critical need to corroborate modelled pressure drops and gas velocities for a selection of pipes and other assets, (e.g. valves), supplying 100% hydrogen at a range of demands and pressures representative of the distribution networks – LP (up to 75 mbar), MP (up to 2 bar) and IP (up to 7 bar) to validate the model results. The methodology for this will be to model pressure drops and velocities for a range of pipe diameters, flows and starting pressures and then to measure these under the same conditions using test pieces installed in the testing network.

The test network will be flexible to insert test pieces into above ground test areas at the three distribution pressure levels with the required instrumentation to record the pressure drop and gas velocity across the test piece.

Table 1: Indicative demonstrations on the LP network demonstrates the flexibility of the testing that will be undertaken and what data would be validated. All values below are based on 100 m lengths.

	Demands in scm/h hydrogen. All values based on 100 m lengths							
	10	50	100	400	1,000	2,000	4,000	10,000
ΔP mbar								
63mm PE	0.06	1.35	4.39	49.97				
90mm PE	0.01	0.21	0.67	7.39	37.61			
125mm PE	0.00	0.04	0.14	1.53	7.64	26.34		
180mm PE	0.00	0.01	0.03	0.27	1.35	4.58	15.81	
250mm PE	0.00	0.00	0.00	0.06	0.27	0.92	3.14	16.30
355mm PE	0.00	0.00	0.00	0.01	0.05	0.17	0.59	3.01
Velocity m/s								
63mm PE	1.15	5.76	11.54	48.25				
90mm PE	0.52	2.59	5.19	20.89	53.77			
125mm PE	0.27	1.34	2.67	10.71	26.94	54.85		
180mm PE	0.13	0.65	1.29	5.16	12.93	25.93	52.42	
250mm PE	0.06	0.32	0.64	2.54	6.36	12.73	25.44	64.58
355mm PE	0.03	0.16	0.32	1.26	3.15	6.31	12.61	31.63

Table 13: Indicative demonstrations on the LP network

D.3.5. *Phase 2a(vi) Update QRA*

The H21 QRA will be updated with new information as it becomes available including results from Phase 2a – Appraisal of Network Operation to ensure the QRA is up to date at each stage of the project and a full view of up to date risks are available prior to commencing the next round of tests.

D.4. Phase 2b – Unoccupied Network Trials

Summary: Nationally, operational hydrogen experience is limited to industrial applications as there are no gas distribution networks supplying 100% hydrogen to homes at present. For a live community trial to progress it is essential that this gap is addressed, and a programme of testing is developed and agreed by all project partners. The programme will also look to resolve any remaining engineering risks that may occur at the time of live community trials and subsequent conversion.

By conducting the unoccupied network trials, it would provide further confidence moving to the community trails for the Duty Holders and HSE who are ultimately responsible for the sign-off of the Safety Case. The trials would also instil confidence amongst other stakeholders, customers and the industry workforce.

It is proposed that the trial H21 NIC Phase 2b – Unoccupied Network Trials will remain purely focused on network operations and assets upstream of the ECV, and will therefore not impact any customers gas supplies.

In order to progress with confidence onto a live community trial, a trial of conversion and operation of an existing, in-situ, undisturbed gas network under controlled conditions (unoccupied) is imperative. H21 NIC Phase 1 testing will highlight any particular assets that could cause a problem for the conversion to 100% hydrogen in terms of compatibility and leak tightness. The Phase 2b unoccupied trials of the Network Operations will validate and further develop the learning from previous phases by converting and operating an existing, undisturbed, unoccupied part of the network but within a controlled environment that will not impact on customers supplies. The selected site would have a range of different assets representative of the networks post IMRRP with relevant asset materials and components, on different pressure tiers. By utilising an undisturbed part of the network, the Project would be able to determine an effect of contaminates and stagnant odorisation present that only a mature in-situ asset would otherwise provide. These contaminates would include dust, swarf and other main debris that could be affected by the increase in velocities with the change to hydrogen.

Of the numerous hydrogen projects currently being undertaken in the UK, none are undertaking physical demonstrations of 100% hydrogen operations on a fully comparable existing live network asset.

The H21 NIA Field Trial shall determine the selection criteria and location for an unoccupied network site and identify any modifications to the new site, along with rationale for the selection process.

The site must be representative of a typical small-scale network, as would be post 2032. Therefore, in consideration of the current IMRRP programme the site will need to contain both PE and metallic assets and ideally existing pressure reduction equipment. This work is currently being undertaken under the existing H21 NIA Field Trials project. At present, all suitable sites identified to date, with sufficiently representative example of assets in situ with no end users connected have not been available due to other land issues, predominantly re-development plan. The search has also taken into consideration site security and customer and environmental impact which has reduced the amount of options available.

Procedures will be demonstrated on this unoccupied network to provide further confidence that safe operation of the network can be managed. Prior to conducting the occupied network trial, a suitable safety management system including a set of bespoke trial procedures and training and competency assessments will be developed and rolled out to relevant personnel. The evidence for the safety management system will be drawn from the technical evidence gathered in Phase 2a – Appraisal of Network Operations.

This stage will be critical in the development of the competencies required of operational colleagues, to ensure that the operation and maintenance of a re-purposed hydrogen network is as safe as it is today running on natural gas.

Phase 2b – Unoccupied Network Trials will provide the confidence and final piece of evidence to industry, stakeholders and end users that re-purposing the GB gas distribution network to 100% hydrogen is safe, efficient and manageable.

It is recognised that close collaboration on this phase with the BEIS Hy4Heat programme will potentially allow for the site to also be utilised for downstream demonstrations, again in an environment where there will be no customer impact. This will enable the decarbonisation of the gas network to move onto the next phase, including live community trials with end consumers with the required evidence, confidence and public acceptance required.

There are several key objectives for Phase 2b – Unoccupied Network Trials which are defined below;

- To demonstrate the findings from Phase 1 and Phase 2a on an existing unoccupied site demonstrating network operations in terms of conversion, new connections, network leakage response, detection and repair on a more representative network in a real-world environment.
- Validate model network flows and pressures on a larger scale network on assets undisturbed since time of installation.
- Provide a platform to promote and demonstrate a hydrogen network in action.
- To review any effect on the hydrogen from contaminants and stagnant odorization present in a mature natural gas asset of scale.
- Greater understanding on the behaviours of hydrogen and other utilities will be better understood as a wider range of surrounding utilities and street furniture would likely be present. Leakage migration results from testing at “Spadeadam” in

Phase 1B would not be validated in the real-world environment for example when leaks occur in settled and undisturbed ground over decades.

- Gain greater confidence on the performance of assets installed to standards not representative of those practiced today.
- Minimise any potential delay in progressing to future community trials if the Network Duty holders insist on unoccupied live tests prior to roll out of Community Trials.
- Identify issues in relation to dust and other mains debris movement found in existing assets may not otherwise be evident in an idealised environment.
- Provide "real world" training for Network Operations staff prior to the Community Trials
- To ensure preparedness for the unexpected at point of conversion, as networks are complex by nature and not always what records indicate. While observing behaviours of Field staff, Operational personnel will gain first-hand experience and be ready to identify issues within the buried networks that would likely cause delays and increased disruption to customers at point of actual conversion.

Below is a detailed technical description of how these objectives shall be met.

Methodology

D.4.1. *Phase 2b(i) Site Set up & Construction Modifications*

Prior to mobilisation to site, various planning, design and project management preliminary works will be required and include the following key areas of work;

Community engagement: As previously mentioned, hydrogen research has to date (HyDeploy2) been undertaken in controlled test locations outside of the public sphere. This has been for the right reasons in ensuring that public safety remains a priority during essential research and testing work. However, if hydrogen is going to provide the pivotal role in decarbonisation of heat there will need to be public support and acceptance. This phase will raise the awareness of hydrogen and the level of industry research currently being undertaken in the UK and will further generate engagement with external stakeholders and members of the public. By undertaking and involving stakeholders in the programme, potentially in collaboration with Hy4Heat, the unoccupied trial site will serve as a platform to help consumers understand the impact of such a conversion when it arrives in their area and will allow consumers to fully understand the implications of the conversion process and any likely disruption in terms of supply interruption, roadworks and changes to the home (subject to Hy4Heat involvement) that will be necessary.

Insurance & legal agreements: Arrangements shall be made to ensure all aspects of the unoccupied network trials are fully compliant with all necessary regulations. This will involve detailed discussions, correspondence and agreements with insurance providers and local authorities by the project team.

Security: Although the site to be selected shall be unoccupied, there are still inherent security risks with potentially occupied neighbouring networks and communities. Public safety is paramount to the Project and site access, security and communications to the public shall be risk assessed and appropriate mitigations put in place. Currently it is envisaged the site shall have full perimeter fencing with comprehensive security measures put in place.

Planning & onsite pre-validation works: Once a site has been selected it is imperative to undertake pre-conversion surveys to validate the preliminary desktop findings as part of the H21 NIA Field Trials project deliverables. This shall include a programme of invasive and non-invasive operations to validate the networks capability and verify suitability prior to conversion. Operations envisaged at this time include leakage surveys, internal CCTV surveys, trial excavations and pressure decay and soundness testing. The results of these pre-works shall validate suitability of the network, e.g. minimal leaks, free from major internal defects and identification of any minor remediation required etc., providing baseline variation results for comparison during the conversion and subsequent operations.

Gas supply: Once the site location is agreed, finalisation of the design and build of the equipment needed to supply gas shall be completed. Currently the project expects hydrogen to be tankered in and stored on site temporarily for the trials unless the site most suitable for conversion is near an existing hydrogen supply source. Transporting and storing hydrogen on site brings additional transport and safety risks depending on the volumes required for the network, including traffic management issues. All issues surrounding gas supply shall be managed and solutions provided at this stage of the works.

Measurement points: Locations for control and measurement points shall be defined. These locations shall be validated and installed as part of the site set up works.

Control centre: In order to monitor and control all the tests defined in the MTP, a temporary control centre shall be built on site. Exact requirements of the control centre shall be determined in the detailed design.

Risk assessment: All elements of the unoccupied network trials shall be risk assessed, documented and mitigations put in place in collaboration with all project partners. This will be built around risks identified from Phases 1a & b, 2a – Appraisal of Network Operations and the H21 NIA Field Trial project, taking cognisance of any additional site-specific and specific point of work risks identified throughout the works.

Training: With the site being in an unoccupied area of the existing GB gas network, it is more than likely that additional operatives shall be required over and above current operatives being used at Spadeadam, Phase 2a – Appraisal of Network Operations. A gap analysis of training and competence shall be carried out and appropriate classroom/on-site training developed and delivered to ensure a competent workforce to deliver this critical phase of the work. This shall be completed and could be used to provide the basis of future community trials and 100% network conversion. Any operational training materials that are developed will be shared between the GDNs providing value for money and facilitating critical knowledge dissemination.

In addition to the Phase 2b site team, the adjacent existing natural gas network operatives shall be briefed and trained as required on a select quantity of emergency procedures and be informed of what tests will be carried out when and for how long.

D.4.2. *Phase 2b(ii) Network Conversion (Commissioning from Natural Gas to H_2)*

The exact sequence of operations to be conducted as part of the commissioning, conversion and decommissioning phases is still to be determined through the detailed design, the aim of which is to demonstrate safe and efficient conversion and commissioning of the re-purposed network. The network would enable several different options to be trialled prior to conducting it on a real network, including emergency response scenarios and operations of a routine and non-routine nature.

It will also highlight and identify issues relating to commissioning and normal operation of the re-purposed hydrogen network, for example contaminants from natural gas such as dust, odorant and Mono Ethylene Glycol (MEG).

As part of the conversion process a pre and post-conversion leakage survey shall be undertaken to ensure the performance of the assets remains as expected.

D.4.3. *Phase 2b(iii) General Operation & Maintenance Testing*

The unoccupied network shall be managed and operated 'as normal' to establish that current equipment used for pressure reduction to domestic supplies remains unaffected on a real network or detail any changes in performance and validate the results of Phase 1b in the event of leakage from a real network in a public environment (albeit controlled). Ongoing leakage surveys shall be undertaken on the converted network.

D.4.4. *Phase 2b(iv) Dealing with Emergencies*

A series of tests shall be simulated as part of an updated MTP to deal with known emergency operations. This will be used to demonstrate that it is possible to locate, make safe and repair the network as under normal natural gas emergency conditions.

This would enable the simulation of these emergency situations in a "real world" environment and further build the experience and competencies of our emergency response field staff.

Additional tests may also be required as identified in the safety based QRA and ongoing analysis and comparison of natural gas/hydrogen tests being conducted in Phase 1b and Phase 2a – Appraisal of Network Operations.

D.4.5. *Phase 2b(v) Demonstration of Network Extension/Replacement*

The unoccupied network shall also be subject to extension/replacement works to demonstrate that the network can be expanded, as per customer demand, for new connections and continue to replace the network efficiently, as required by any future mains replacement policy or condition requirement.

D.4.6. *Phase 2b(vi) Identification of Training, Skills and Competency Gaps*

Throughout all the demonstrations, tests and learnings identified above, information shall be gathered regarding competency and training gaps in the safe conversion and ongoing maintenance and management of a hydrogen network. This shall provide another platform to further enhance the training learnt on Phase 2a – Appraisal of Network Operations. These gaps shall form the basis for further development outside of this Project to determine the necessary skills and competencies of managers and operatives need for future live community trials.

D.4.7. *Phase 2b(vii) Update QRA*

These trials will also further inform the QRA work already undertaken to date and will allow for further tests to be undertaken in an area with in-situ assets and pre-existing conditions. For example, the leakage models would be further developed by utilisation of existing confined spaces such as street furniture, ducts, sewers and vacant housing stock. Further migration tests will also be further validated against real life conditions, for example how gas would migrate along other utilities and areas of previous ground disturbance such as recently reinstated openings and trenches.

D.5. Phase 2c - Combined QRA

Summary: Following successful demonstrations on the micro-grid and unoccupied network site, it is expected that a more robust basis of safety and network modelling will be available for the use of hydrogen in the existing distribution network up to the ECV. Hy4Heat have been, and continue to, investigate the BoS for operations 'after the ECV' and, in order to provide a full overview of risk for the conversion to hydrogen, it is proposed that H21 shall compare, analyse and align the QRAs from the two innovation projects. This will need to be done as soon as possible to ensure compatibility of the adjoining systems (upstream/downstream of the ECV) to provide a full overview of risk prior to commencing live community trials where the two innovation projects, Hy4Heat and H2, 1 shall combine forces and demonstrate the conversion project on a live occupied section of the GB gas network.

Depending on the outcome of the combined risk assessment, additional safety mitigations may be required for the live community trials or additional tests may need to be carried out.

There is one key objective for Phase 2c which is defined as;

- To link the H21 QRA with the Hy4Heat QRA downstream of the ECV to get an overall view on risk and what, if any, mitigations might be needed for the first live community trial and overall on the network
- Below is a detailed technical description of how this critical objective shall be met.

Methodology

D.5.1. *Phase 2c(i) - Engage & Combine QRA with Hy4Heat*

The H21 QRA Lead shall engage with Hy4Heat to discuss the approaches taken for the two QRAs and influence the Hy4Heat approach to align the format of the outputs and establish a methodology for combining the QRAs. This will combine the Hy4Heat QRA (assessing risks to the public from the installation pipework and appliances downstream of the ECV in residential and commercial premises) with the H21 QRA model developed in H21 NIC Phase 1 (assessing risks to the public from the network pipes and components upstream of the ECV). The combined results will provide a complete assessment of the risks to the public from a converted network supplying 100% hydrogen.

D.5.1. *Phase 2c(ii) - Update H21 QRA Model*

Further work shall be required to update the H21 QRA model with new information as it becomes available including results from Phase 2a and Phase 2b and other ongoing projects such as Hy4Heat to avoid duplication (including SGN H100 for a new build all PE network), as appropriate. This will involve phased reviews of projects and continued gathering of network data to address gaps in knowledge from experience of gas releases (pipeline leak frequency and distribution of hole sizes) and update the H21 QRA model accordingly.

This phase shall run concurrently throughout Phase 2 alongside Phase 2a and Phase 2b to ensure the safety risk model is up to date at each stage of the project and a full view of up-to-date risks are available prior to commencing the next round of tests during the phases.

D.5.2. *Phase 2c(iii) - Risks for 100% hydrogen and Mitigation*

Once the QRA models have been updated, the combined QRA shall be applied to predict the risk impact of conversion to 100% hydrogen and the effect of reasonably practical risk mitigation measures on the overall risk as appropriate.

This will involve updating the comparison of risk between alternative pathways to achieving zero carbon energy supply which was initiated in H21 NIC Phase 1.

During this critical phase, gaps in information between the QRAs may be identified, and elements of the full risk models may still be unknown. In the unlikely event of this occurring, additional tests, modelling or mitigations may be required in order to progress with the live community trials. These shall be recorded and programmed for future pre-works to the live community trials.

D.6. Phase 2d - Social Sciences

Summary

For a successful 100% hydrogen conversion it is important that customers are equipped to make choices about their future energy supplies. Misunderstanding and misinformation could lead to poor customer choices or unwarranted concern. In a worst-case scenario, where widespread misunderstanding and misinformation lead to a wholesale rejection of conversion, the option of hydrogen could be lost entirely.

The social sciences research will provide insight into customer perceptions and produce resources that can be used to communicate with them. To do this, we need to establish how to frame and communicate complex information in a way that empowers customers rather than causes unwarranted confusion or negativity. The output of the research will be a suite of resources that NGN can use to communicate effectively with the public about a hydrogen conversion so that they can make an informed choice about their post-conversion energy supply. We will:

1. Produce a glossary of terms that explain the key concepts underpinning a hydrogen conversion and the safety testing that has been completed.
2. Produce an engaging and easy-to-understand animation that explains the reasons for a hydrogen conversion and what it involves.
3. Develop a beach-to-meter display that will be used at community engagement events to aid explanations of how hydrogen is stored and transported, and the practicalities of how the conversion is achieved.

These objectives will be achieved using the following research methods:

D.6.1. *Co-production workshops*

Workshops will be held with new members of the public, joined by hydrogen professionals. Together they will co-produce materials that explain the issues and answers the questions that people have. We will hold six different workshops in three different locations. The first three workshops will identify the terms that need to be explained and will develop draft explanations of these terms. The second three – attended by different members of the public – will further develop the drafts into short, easy-to-understand definitions and identify any infographics that will aid understanding and acceptance. Each workshop will last two hours and will comprise eight members of the public, two researchers and two experts. There will be a quota for the public, including age, gender, segmentation group (with a higher quota for groups 2 and 3), socio-economic status and educational level achieved. The quota ensures that the materials engage a wide range of people, including the 60% of the population (as identified in Phase 1) who are not easily engaged on this issue and who, because of misunderstanding or misinformation, could reject hydrogen as a solution. The workshops will involve a series of activities to identify terms and to iteratively develop clear and easy-to-understand explanations. We will also develop and test an easy-read version leaflet that makes greater use of graphics and will explain the conversion process for people who have difficulties reading or understanding English.

D.6.2. *Storyboard groups*

We will then hold three focus groups to: co-design a script and storyboard to explain the hydrogen conversion; explore responses to these materials; and refine the draft into a final version of the animation. The first group will develop a draft script and initial storyboard ideas, following this group, a first draft of the animation will be produced. The second focus group will provide feedback on the content, timing, and voiceover. This will enable a final draft of the animation to be produced, which will be explored during the third focus group. This will identify any final changes required to make the animation engaging and to help customers understand the reasons for and the process of a hydrogen conversion. Each group will last an hour and will include a quota (as above) to ensure that the final animation increases understanding of the conversion process and confidence to make an informed choice about future energy sources.

D.6.3. *Display groups*

This process will mirror the Storyboard groups in that it is an iterative process of developing initial ideas of what to include in the beach-to-meter display and how to portray the processes involved. Three different groups will be held, in three different locations, each with different members of the public. Over the course of the three groups we will develop a prototype display that will help the public to understand how hydrogen is stored and transported, and the practicalities of how the conversion will be achieved in their area.

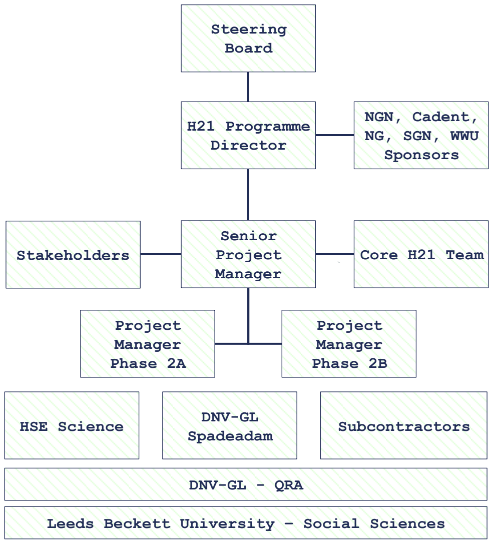
D.6.4. *Online survey*

We will conduct an online survey with a representative sample of the UK population, with a target of 1000 respondents. The survey provides two functions. First, it will provide a randomised controlled trial of the effectiveness of the animation. Respondents will be randomised to view the animation during the survey, or not to view it (although to ensure nobody is disadvantaged, they will be shown it at the end of the survey). This will enable us to test the extent to which the animation increases understanding about a hydrogen conversion and confidence to make an informed choice about their future energy supply. The second aspect of the survey will be to provide a statistical model to identify the importance of price, appliance cost, safety, disruption and sustainability in reaction to a 100% hydrogen conversion. This will provide statistical evidence on the impact of messages around price, cost, safety, disruption and sustainability, and will also model the effects of socio-demographics. This may take the form of a conjoint analysis, which will produce a model in with the ability to run scenarios predicting the effect of changing price, cost and disruption on the extent to which people support the change. The survey will also identify any socio-demographic groups who find the explanations more difficult to understand, and so will assist NGN's engagement team when communicating with different groups of customers.

Appendix E. Project governance and organogram

Project management is provided by a multi-disciplined project team responsible for co-ordinating the day-to-day operations of the Project. This will include management of subcontractors and programme, coordinating and reporting to the Project Board and Steering Board, acting upon decisions with relation to budget management, submitting requests for milestone completion, sanctions to progress to subsequent project stages etc. Project Board meetings of the participants will be held monthly. A summary of the proposed management structure for the Project is shown in the Figure 1: Project organogram.

The core team will be made up of a Senior Project Manager and commercial functions reporting directly to the H21 Programme Director. They will be engaged by Northern Gas Network (NGN) and shall produce monthly reports summarising the progress of the Project in accordance to the standing agenda of the Project Board meetings. A copy of the monthly report will be circulated to each member of the Project Board with written notice for the relevant meeting by the Senior Project Manager. Additionally, a Steering Board update will be prepared and delivered at quarterly Steering Board meetings. A copy of the update will be circulated to each member of the Project Board with the written notice for the relevant meeting by the Senior Project Manager. All other sub-teams will report back to the Senior Project Manager, who will ensure appropriate communications are delivered throughout the Project.



The GB Gas Distribution Networks (GDNs) team for Phase 2a – Appraisal of Network Operations will have a Spadeadam Project Manager responsible for overseeing construction, facilitating the testing and managing the budget for the Spadeadam site. This Project Manager will also be responsible for delivery of the H21 NIA Phase 2 – Field Trials design and enabling work.

The GB GDNs team for Phase 2b – Unoccupied Network Trials will have a remote location Project Manager responsible for overseeing design, construction, facilitating the testing and managing the budget for the remote location site.

The H21 Programme Director is accountable for the successful allocation of milestones and allocation of stage funding under the NIC allowance.

The Project Board will meet on a monthly basis and will be attended by the H21 project team and representatives from each of the primary project partners. The Chair of the Project Board shall be the H21 Programme Director for NGN. Should the Chair not be available, the H21 Senior Project Manager will act as Chair.

The role of the Project Board is to review overall progress of the Project and to assure delivery of all activities undertaken on the Project to scope, time and budget. Members may participate via teleconference, video conference or other technological means where necessary. Should a nominated primary project partner become unable to attend, the member may appoint an alternate.

The Project Board shall provide assurance on:

- Safety and environmental management – incidents, lost time injuries, any breaches of environmental controls etc.
- Progress against deliverables and plan – mitigation of issues arising, review of open issues, sanction for closing open issues.
- Review of subsequent plans for coming six-month period and potential to accelerate activities or manage issues arising.

- Evidence of project task completion and review of achievement of research outcomes.
- Review progress against budget, risks register (proposed inclusion or removal of, change in impact/probability), communications plan etc.
- Evidence of project milestone progression as appropriate.

Minutes of the meetings of the Project Board will be prepared by the H21 Project Officer and sent to each of the parties within fourteen days after each meeting.

The Steering Board will meet on a quarterly basis and comprises representatives nominated by each of the collaborating GB GDNs and the primary project partners. The Chair of the Steering Board shall be the H21 Programme Director for NGN. Should the Chair not be available they shall delegate to one of the other collaborating GDNs as appropriate.

The role of the Steering Board is to assure delivery of all the activities undertaken on the Project to scope, time and budget and to provide overall direction of the work. Members may participate via teleconference, video conference or other technological means when necessary. Should a nominated member become unable to attend the member may appoint an alternate. Any alternate attending for a period of more than two months is to be approved by the Chair.

The Steering Board shall provide assurance on:

- Safety and environmental management – incidents, lost time injuries, any breaches of environmental controls etc.
- Progress against deliverables and plan – mitigation of issues arising, review of open issues, sanction for closing open issues.
- Review of subsequent plans for coming six-month period and potential to accelerate activities or manage issues arising.
- Evidence of project task completion and review of achievement of research outcomes.
- Review progress against budget, risks register (proposed inclusion or removal of, change in impact/probability), communications plan etc.
- Evidence of project milestone progression as appropriate.

Meetings of the Steering Board will be convened with at least fourteen days' written notice in advance. That notice must include a standing agenda and additional agenda items on request of any project partner. Minutes of the meetings of the Steering Board will be prepared by the H21 Project Officer and sent to each of the parties within fourteen days after each meeting.

Each Steering Board Partner will have one vote. Decisions will be taken by a simple majority (in a tied vote, the H21 Programme Director will have a casting vote), except where a decision necessitates a change to the Project plan or a change to the allocation of any funding or change to any contribution. In any of those cases, any decision must be unanimous and may only be made where the representatives of all the partners are present.

Contractual Arrangements: The GB GDNs have a well-developed and proven collaboration agreement, which has formed the basis for three NIC projects to date. This has been reviewed by the Project Partners and will form the basis for this project. A summary of the proposed contractual arrangements is shown Figure 7: Proposed contractual arrangements summary.

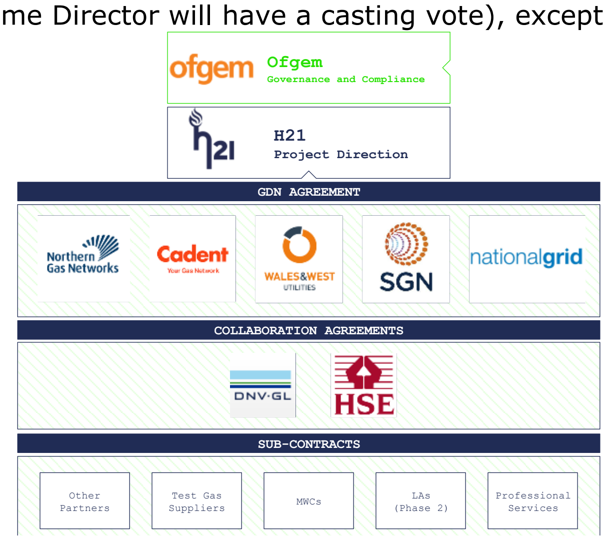
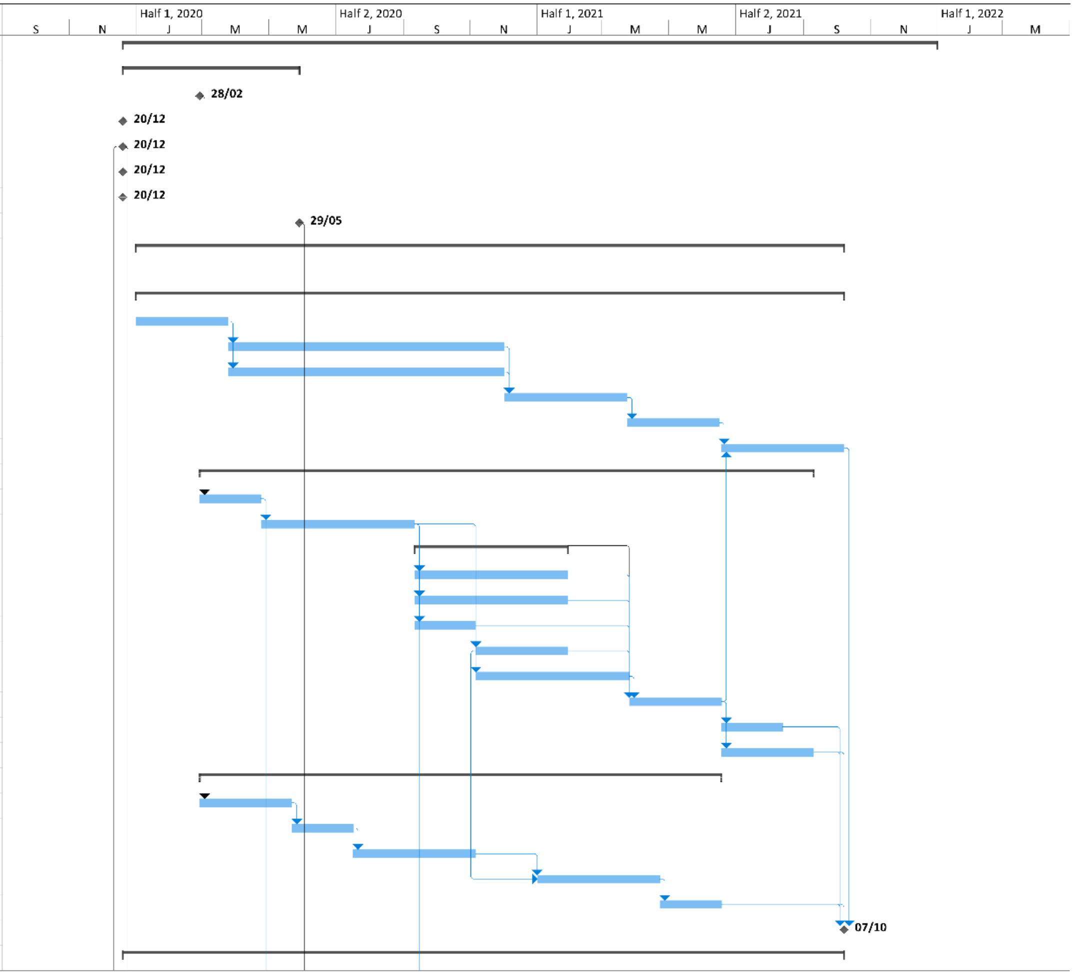


Figure 7:Proposed contractual arrangements summary

Appendix F. H21 Phase 2 Programme

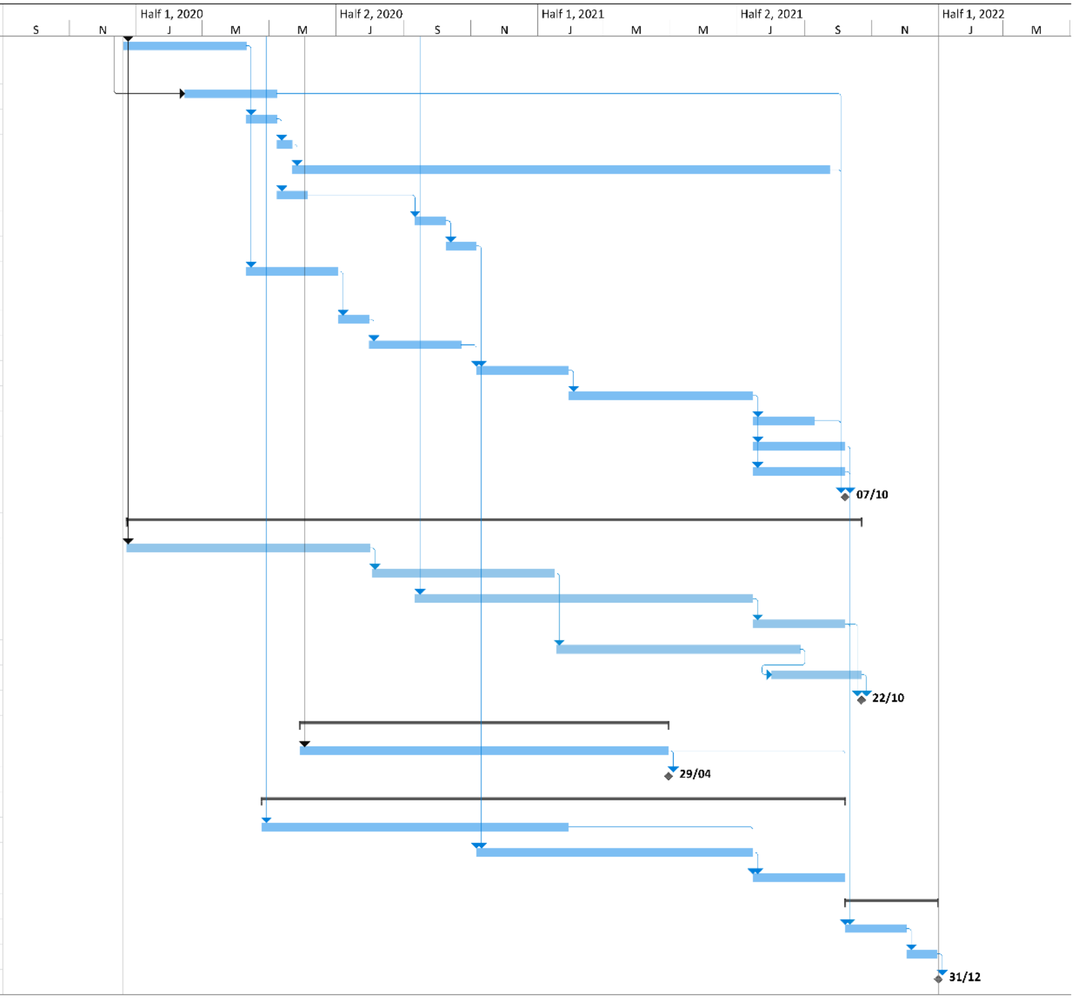
ID	Task Name	Duration	Start	Finish
1	**Phase 2**	**531 days**	**Fri 20/12/19**	**Fri 31/12/21**
2	**Prerequisites**	**115 days**	**Fri 20/12/19**	**Fri 29/05/20**
3	Detailed Design - Micro-Grid (NIA Project)	0 days	Fri 28/02/20	Fri 28/02/20
4	Master Test Plan (MTP) - (NIA Project)	0 days	Fri 20/12/19	Fri 20/12/19
5	Network Operations Site Selection (NIA Project)	0 days	Fri 20/12/19	Fri 20/12/19
6	Initial Literature Review (NIA Project)	0 days	Fri 20/12/19	Fri 20/12/19
7	Identify Procedures that require further Work (NIA Prc	0 days	Fri 20/12/19	Fri 20/12/19
8	Completion of Phase 1 Report	0 days	Fri 29/05/20	Fri 29/05/20
9	**Phase 2a - Appraisal of Network Components and Procedures**	**462 days**	**Wed 01/01/20**	**Thu 07/10/21**
10	**Scientific Programme**	**462 days**	**Wed 01/01/2**	**Thu 07/10/21**
11	Design scientific programme and Update MTP	3 mons	Wed 01/01/2	Tue 24/03/20
12	Deliver scientific work	9 mons	Wed 25/03/2	Tue 01/12/20
13	Engage with component manufacturers	9 mons	Wed 25/03/2	Tue 01/12/20
14	Technical support documents - Version 1	4 mons	Wed 02/12/2	Tue 23/03/21
15	Technical support documents - Version 2	3 mons	Wed 24/03/2	Tue 15/06/21
16	Technical support documents - Version 3	4 mons	Fri 18/06/21	Thu 07/10/21
17	**Micro-Grid & Gas Testing**	**400 days**	**Fri 28/02/20**	**Thu 09/09/21**
18	Tender	2 mons	Fri 28/02/20	Thu 23/04/20
19	Construction	5 mons	Fri 24/04/20	Thu 10/09/20
20	**Testing**	**100 days**	**Fri 11/09/20**	**Thu 28/01/21**
21	Testing of Operation Procedures	5 mons	Fri 11/09/20	Thu 28/01/21
22	Testing of Maintenance Procedures	5 mons	Fri 11/09/20	Thu 28/01/21
23	Testing of Buried Assets	2 mons	Fri 11/09/20	Thu 05/11/20
24	Testing for Updating of Models	3 mons	Fri 06/11/20	Thu 28/01/21
25	Re-visit gap analysis & design further testing	5 mons	Fri 06/11/20	Thu 25/03/21
26	Further testing	3 mons	Fri 26/03/21	Thu 17/06/21
27	Update Phase 1 QRA with new test results	2 mons	Fri 18/06/21	Thu 12/08/21
28	Test reports	3 mons	Fri 18/06/21	Thu 09/09/21
29	**Modelling**	**340 days**	**Fri 28/02/20**	**Thu 17/06/21**
30	Analyse models	3 mons	Fri 28/02/20	Thu 21/05/20
31	Validate against methane models	2 mons	Fri 22/05/20	Thu 16/07/20
32	Update for hydrogen	4 mons	Fri 17/07/20	Thu 05/11/20
33	Validate and review model for mico-grid	4 mons	Fri 01/01/21	Thu 22/04/21
34	Report	2 mons	Fri 23/04/21	Thu 17/06/21
35	Completion of Phase 2a	0 days	Thu 07/10/21	Thu 07/10/21
36	**Phase 2b - Unoccupied Network Trials**	**470 days**	**Fri 20/12/19**	**Thu 07/10/21**



Project: H21 Phase 2 Programme
Date: Fri 12/07/19
Rev: 04

Task	Project Summary	Inactive Milestone	Manual Summary Rollup	Deadline
Split	External Tasks	Inactive Summary	Manual Summary	Progress
Milestone	External Milestone	Manual Task	Start-only	Manual Progress
Summary	Inactive Task	Duration-only	Finish-only	

ID	Task Name	Duration	Start	Finish
37	Confirm legal agreement for access with Local Area Authority	4 mons	Fri 20/12/19	Thu 09/04/20
38	Stakeholder Engagement for Remote Location	3 mons	Fri 14/02/20	Thu 07/05/20
39	Develop temporary works design for site testing	1 mon	Fri 10/04/20	Thu 07/05/20
40	Secure Site (Fencing)	0.5 mons	Fri 08/05/20	Thu 21/05/20
41	Site Security (CCTV/Security guard)	17.5 mons	Fri 22/05/20	Thu 23/09/21
42	Preliminary gas main "soundness" test	1 mon	Fri 08/05/20	Thu 04/06/20
43	Prove gas mains 'soundness' test for identified sites	1 mon	Fri 11/09/20	Thu 08/10/20
44	Correct mains / services as required	1 mon	Fri 09/10/20	Thu 05/11/20
45	Design conversion of Remote location for testing purposes	3 mons	Fri 10/04/20	Thu 02/07/20
46	Safety management - FPSAs. Design assurance	1 mon	Fri 03/07/20	Thu 30/07/20
47	Procurement Activity	3 mons	Fri 31/07/20	Thu 22/10/20
48	Construct site (governor, H2 injection points, etc)	3 mons	Fri 06/11/20	Thu 28/01/21
49	Site Testing	6 mons	Fri 29/01/21	Thu 15/07/21
50	Update Phase 1 QRA with new test results	2 mons	Fri 16/07/21	Thu 09/09/21
51	Report	3 mons	Fri 16/07/21	Thu 07/10/21
52	Site demobilisation	3 mons	Fri 16/07/21	Thu 07/10/21
53	Completion of Phase 2b	0 days	Thu 07/10/21	Thu 07/10/21
54	**Phase 2c - QRA**	**480 days**	**Mon 23/12/1**	**Fri 22/10/21**
55	Engagement with Hy4Heat - As Required	8 mons	Mon 23/12/1	Fri 31/07/20
56	Combined QRA model	6 mons	Mon 03/08/2	Fri 15/01/21
57	Update H21 QRA Model From Phase 2a & b - As Requii	11 mons	Fri 11/09/20	Thu 15/07/21
58	QRA Closeout Report	3 mons	Fri 16/07/21	Thu 07/10/21
59	Risks for 100% Hydrogen and Mitigation	8 mons	Mon 18/01/2	Fri 27/08/21
60	Comparison of Risks	3 mons	Mon 02/08/2	Fri 22/10/21
61	Completion of Phase 2c	0 days	Fri 22/10/21	Fri 22/10/21
62	**Phase 2d - Social Science**	**240 days**	**Fri 29/05/20**	**Thu 29/04/21**
63	Social Science Work	12 mons	Fri 29/05/20	Thu 29/04/21
64	Completion of Phase 2d	0 days	Thu 29/04/21	Thu 29/04/21
65	**Stakeholder Engagement**	**380 days**	**Fri 24/04/20**	**Thu 07/10/21**
66	Filming Phase 2a Construction & Testing	10 mons	Fri 24/04/20	Thu 28/01/21
67	Filming Phase 2b Construction & Testing	9 mons	Fri 06/11/20	Thu 15/07/21
68	Final Film Production	3 mons	Fri 16/07/21	Thu 07/10/21
69	**Final Project Report**	**61 days**	**Fri 08/10/21**	**Fri 31/12/21**
70	Develop Report	2 mons	Fri 08/10/21	Thu 02/12/21
71	Final Draft Review	1 mon	Fri 03/12/21	Thu 30/12/21
72	Launch Event	0 days	Fri 31/12/21	Fri 31/12/21



Project: H21 Phase 2 Programme
Date: Fri 12/07/19
Rev: 04

Task | Split | Milestone | Summary | Project Summary | External Tasks | External Milestone | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | Deadline | Progress | Manual Progress

Appendix G. Risk Register

Category	Phase	Risk ID	Risk Description	Impact of Risk	Impact 1-5	Likelihood 1-5	Pre- Risk Rating	Mitigation	Actions	Impact 1-5	Likelihood 1-5	Post-Risk Rating
Health and Safety	2	1	Hydrogen storage and facilities failure.	Possible safety issue.	5	3	15	Designed by competent person. Develop testing and process procedures for safe control of operations.	Identify and follow procedures. Inspection and monitoring of facility.	5	1	5
Commercial	2	3	Variation in the cost of hydrogen/ materials.	Cost implication.	3	2	6	Cost of the project is being carefully managed		1	1	1
Project	2	4	Poor collaboration on project.	Project schedule.	4	2	8	Active project management by Programme Director. Acknowledge lessons learned from Phase 1.	Regular interaction on project at all levels. Support active engagement between projects. Collaborate between Steering Boards.	1	1	1
Project	2	5	Project delivery slippage.	Impact on project completion and milestones.	4	2	8	Active project management of all aspects and regular project updates.	Realistic programme. Involve all stakeholders in programme development.	2	1	2
Project	2	6	Stakeholders not informed on project delivery.	Impact on project success.	3	3	9	Active stakeholder engagement, regular Steering Board meetings and stakeholder sessions.	Development of Stakeholder Engagement Strategy.	2	1	2
Bid	2	19	Under-reach of project deliverables (i.e. not full evidence base obtained).	Impact on project success.	3	3	9	Active stakeholder engagement.	Clear, concise goals with follow on works and expected gap already identified at project start-up.	3	1	3
Project	2	20	Devaluation of deliverables: Government policy changes away from hydrogen.	Impact on Project success.	5	2	10	Deliver in time, stakeholder engagement. Ensure high level project representative attends strategic events.	Align timescales with other key projects.	5	1	5
Bid	2	24	Avoid duplication with other projects.	Duplicated work.	4	3	12	Keith Owen to oversee links with other projects. Make stronger links in NGN between the H21 and HyDeploy teams so lessons can be learnt. Share intelligence from the project team who are working on other projects. Share proposed scope with other projects.	Continued engagement with other projects.	3	1	3
Health and Safety & Technical	2a	8	Specifying appropriate equipment.	Incorrect specification causes technical safety issues.	4	2	8	Careful spec, full HAZOP and safety mechanisms built in and decommissioning of system through site procedures.	Follow site procedures for design specification.	4	1	4
Health and Safety	2a 2b	10	Construction/ fabrication/ installation.	Safety issue.	5	3	15	Specific site procedures and risk assessment operated in accordance with site activities.	Develop and follow site procedures and safe control of operations process.	5	1	5
Health and Safety	2a2 b	11	Risk of hydrogen entering the adjacent natural gas network during trials.	Safety issue.	5	2	10	Detailed process for commissioning/ decommissioning of system **Positive Isolation.**	Test the network in advance.	5	1	5

Category	Phase	Risk ID	Risk Description	Impact of Risk	Impact 1-5	Likelihood 1-5	Pre- Risk Rating	Mitigation	Actions	Impact 1-5	Likelihood 1-5	Post-Risk Rating
Technical	2a/b	12	Inadequate number of tests completed to gain sufficient evidence.	Devalued deliverable.	4	3	12	Seek information from NIA. Master testing/planning developed in association with project partners. Learning from other projects.	Develop MTP prior to project initiation (NIA).	2	1	2
Deliverable	2a/b	40	Lack of support from networks/direct suppliers (e.g. no support for trials) necessitates extra project/site effort.	Cost/schedule.	2	4	8	GDNs and suppliers buy in to MTP development.	Involve GDNs and suppliers in MTP development.	2	1	2
Deliverable	2ai	29	No scientific basis of safety/operational suitability for some procedures to make a relative risk judgement against.	Unachievable deliverable.	4	3	12	Involve stakeholders in the review. Where no scientific BoS for existing procedures is identified either (a) do work to establish this by testing with natural gas (b) take an ALARP approach to the assessment of the new BoS.	Close liaison and involvement with stakeholders.	3	1	3
Technical	2aii	30	Difference in hydrogen gas properties means key components of the micro-grid do not perform.	Cost and programme.	4	4	16	Make desk-based assessment of likely performance before procurement. Staged implementation of components. Actively seek out potentially faulty or non-compatible components.	Develop suitable and sufficient detailed design.	3	1	3
Technical	2aiii	32	Risk of failure of installed components on the gas network which have not previously been tested on hydrogen.	Safety issue.	5	3	15	Suitable risk control measures to be put in place to deal with uncertainty of asset performance e.g. exclusion, turning gas off to approach asset. Offline testing first if appropriate. Use technical & scientific justification of procedures to support case for safety alongside testing. Prioritise those procedures that are of the greatest frequency, highest risk or are central to the conversion process first.	Develop the rig design in parallel with procedures.	3	1	3
Health and Safety	2avi	37	Undefined scope of training and competency to go to unoccupied trials	Safety issues and programme.	2	5	10	Early consideration of training requirements and review.	Add item to programme.	2	1	2
Health and Safety	2b	13	Lack of necessary emergency response for unoccupied trials	Safety issue.	5	2	10	Test conducted in accordance with site procedures. Works will be carried out in accordance with the specific safety management system for the unoccupied trials	Training of emergency teams. Procedures will be assessed in the long term – safety management systems to be developed. Learning from Phase 1 testing will be incorporated into the safety systems.	5	1	5
Health and Safety	2b	14	Conflict with other stakeholders.	Safety issue.	5	2	10	Close liaison with stakeholders.	Identify stakeholders and initiate liaison as soon as field trial site has been identified and agreed.	5	1	5

Category	Phase	Risk ID	Risk Description	Impact of Risk	Impact 1-5	Likelihood 1-5	Pre- Risk Rating	Mitigation	Actions	Impact 1-5	Likelihood 1-5	Post-Risk Rating
Health and Safety & Technical	2b	15	Specifying appropriate equipment.	Incorrect specification causes technical safety issue,	4	2	8	Careful spec, full HAZOP and safety mechanisms built in and decommissioning of system through NGN/PM/GL/ 5/G17 process or hydrogen equivalent.	Agree design assurance process.	4	1	4
Health and Safety	2b	16	Access to site, vandalism.	Possible safety issue.	4	5	20	Site will be fenced with 24hr security.	Develop and follow procedures and monitoring of site.	4	2	8
Health and Safety	2b	17	Risk of incorrect purging operation - mixing hydrogen, air and natural gas.	Safety issue.	5	2	10	Seek information from Phase 2a. Develop detailed process for commissioning and decommissioning.	Develop/adopt safe control operations.	5	1	5
Deliverable	2b	18	Identification and authorisation for suitable field trial locations.	Failure of key deliverable. Schedule and cost.	4	5	20	Working with other networks and hydrogen projects. Amend scope for field trial.	Evidence from Phase 1 issues written into bid.	4	1	4
Deliverable	2b	48	Local objections to unoccupied trials being undertaken.	Trial delayed – programme and cost.	5	4	20	Strong engagement plan, early in programme. Lessons learned from fracking, etc.		3	1	3
Deliverable	2d	44	Difficulty in recruiting participants for the Social Sciences study into the public understanding of hydrogen conversion.	Reduced learning leading to miscommun-ication of aims of project.	4	2	8	Early engagement and recruitment of participants		2	1	2

Appendix H. Cost breakdown

Work Package	Total
Core Team	
Project Management – Core Team	£849,348
SUB TOTAL	£849,348
Phase 2a – Appraisal of Network Operations	
Project Management	£311,750
Procedures Review	£821,283
Site Activities	£2,681,672
Modelling	£47,056
SUB TOTAL	£3,861,761
Phase 2b – Unoccupied Network Trials	
Project Management	£262,750
Site Activities	£2,277,248
SUB TOTAL	£2,539,998
Phase 2c – Combined QRA	
Analysis and modelling	£276,593
SUB TOTAL	£276,593
Phase 2d – Social Science	
Social Sciences	£120,000
SUB TOTAL	£120,000
Dissemination of Results	
Dissemination of Results	£191,147
SUB TOTAL	£191,147
TOTAL (Including DNV GL contribution)	£7,838,848
TOTAL (Excluding DNV GL contribution)	£7,613,848

These are the costs associated with each of the phases

Test Phases	ISP Totals	NIC Totals
Phase 2a – Appraisal of Network Operations	£4,500,000	£4,349,999
Phase 2b – Unoccupied Network Trials	£2,500,000	£3,028,236
Phase 2c – Combined QRA	£500,000	£308,603
Phase 2d – Social Science		£152,010

Appendix I. Project Partners

I.1. Gas Distribution Networks (GDNs)

There are eight GDNs, each of which covers a separate geographical region of Great Britain. Across England, Scotland and Wales there are over 282,000km of gas pipes supplying over 21.5 million gas customers. These eight networks are managed by the following companies:

- Northern Gas Networks Limited (NGN) – North East England (including Yorkshire and Northern Cumbria).
- Cadent – West Midlands, North West, East of England and North London.
- Wales & West Utilities Limited (WWU) – Wales and South West England.
- SGN – Scotland and Southern England (including South London).

I.2. Gas Transmission Network

Britain's gas transmission network, the National Transmission System (NTS), is the high-pressure gas network which transports gas from the entry terminals to gas distribution networks, or directly to power stations and other large industrial users. It is owned and operated by National Grid Gas plc (NG).

I.3. Key Project Personnel

Tim Harwood: H21 Programme Director

Tim has 39 years' experience in the UK gas industry covering a wide range of operational and project roles across all pressure ranges and asset types covering distribution and transmission. His current role is Head of Programme Management at Northern Gas Networks (NGN) reporting to the CEO as part of the senior leadership team. He has responsibility for programme management across maintenance, capital projects, repex and connections as well as responsibility for H21 an Ofgem sponsored project looking at how hydrogen can play a part in the decarbonisation of energy networks.

Previously working for 8 years in National Grid Transmission (NGT)he held a number of senior roles as pipeline engineer, project delivery engineer and engineering manager. In a long career he has also held a number of operational roles within gas distribution covering pressure control & storage, mains replacement and emergency response.

Mark Danter: Senior Project Manager

A highly experienced Chartered Engineer, Mark has a proven track record of delivering multi-disciplinary project programmes including water, LPG, biodiesel, ethanol and white fuels, as well as methane.

Mark has worked on several innovation and pilot projects within the gas industry and took on the role of Project Director for conversion from LPG to natural gas in Douglas, Isle of Man. Mark is now Senior Project Manager for the H21 suite of projects.

Russ Oxley: Project Manager Phases 2a and 2b

Russ has spent his entire career working in the gas distribution industry ensuring major mains replacement, diversion and CAPEX projects are delivered to the highest levels of safety performance, efficiency and customer satisfaction.

As H21 Phase 1a and 1b Project Manager, Russ is responsible for ensuring that critical safety-based evidence is gathered from a programme of strategic tests undertaken at two new purpose-built H21 test facilities in Buxton, Derbyshire and Spadeadam, Cumbria.

Alastair Cargill: H21 Strategic Modeller

Alastair is the Senior Network Analyst on the H21 suite of projects with responsibility for modelling of the hydrogen transmission system and the integrity of, and conversion strategy for, the West Yorkshire distribution network.

Alastair also supported the UK GDNs in developing hydrogen conversion modelling in their businesses. Alastair joined the H21 team at the start of the Leeds City Gate project in 2016. Before this, he worked as a Network Analyst for 15 years at NGN, designing reinforcement and REPEX projects for large diameter mains.

Damien Hawke: Director of Future Networks

Damien is a Chartered Engineer with over 17 years' gas industry experience. Damien joined Cadent and its predecessor companies as a Graduate Trainee in 2000 and has held numerous positions across the group, specialising in operational and commercial leadership roles and delivering significant change projects. Damien has a degree in Chemical Engineering from the University of Leeds.

Chris Clarke: Future Strategy Director

A Chartered Engineer and a Fellow of the Energy Institute. Chris has over 30 years' experience within the UK energy industry and is currently Energy Strategy Director at Wales & West Utilities. Chris is responsible for the WWU future of energy strategy and the long term approach to asset investment and has recently led multiple research projects on the lowest cost pathway to decarbonise heat, power and transport.

Angus McIntosh: Director Energy Futures at SGN

Following graduation from Aberdeen University, Gus started working for BG Group some 20 years ago. He has since performed a variety of roles in gas distribution, including asset management, network design, engineering policy, operations and strategy. For six years he headed up SGNs Innovation & New Technology team before being appointed Director of Energy Futures in 2018, with a wider remit to push the frontiers of decarbonisation of energy.

Key breakthroughs have included biomethane to gas grid (Didcot) the first in the UK, keyhole technology (the core & vac, iCore), robotics, real-time networks and gas quality (Oban – Opening up the Gas Markets Project) and 100% hydrogen projects in Scotland. He currently chairs the UK Gas Quality Standard working group for IGEM, which has been set up to facilitate a change to the Gas Safety Management Regulations (GSMR) to allow a wider range of gases to be allowed into the GB gas distribution network, including hydrogen. Gus is also a director of the Scottish Hydrogen and Fuel Cell Association.

Anthony Green: Head of Engineering & Asset Management – National Grid

As Head of Engineering & Asset Management at NG, Tony has responsibility for asset strategy, investment, engineering and innovation. Tony is leading the thinking on the options for the gas transmission network to play its role in the pathway to net zero through decarbonising the network either through hydrogen blends or even a full transition to hydrogen.

A Civil Engineer by degree, Tony has worked in the utilities and infrastructure sectors for over 25 years. He began his career at Severn Trent before moving to Advantica, Germanisher Lloyd and then DNV GL in a variety of business and sector leadership roles, providing a broad range of advisory services and asset management solutions.

Tony is a Chartered Engineer, a Fellow of both Chartered Institution of Water and Environmental Management (CIWEM) and IGEM and serves on the boards of both The European Gas Research Group (GERG) and Marcogaz. Tony became IGEM President in May 2019.

I.4. Key Project Partners

DNV GL

DNV GL is an independent organisation with dedicated technical and risk professionals with a purpose to safeguard life, property and the environment, serving a range of industries, with a special focus on oil and gas sectors. DNV GL has undertaken research and development for the UK gas industry for the past forty years; a large part of this expertise came from the British Gas Research and Development business.

DNV GL has a world-wide reputation for understanding and investigating hazards associated with the energy and chemical processing industries and undertaking safety-related product testing. Their knowledge is combined with well-established and validated risk and consequence assessment techniques, to offer consultancy services to customers supporting safe and cost-effective operations for a wide range of potentially hazardous activities that they undertake. DNV GL's unique Spadeadam Testing and Research Centre features some of the world's most advanced destructive and non-destructive test facilities.

Dr Mike Acton

Mike has worked for over 25 years at DNV GL (formerly British Gas Research and Technology and subsequently Advantica) on safety and environmental issues in the oil and gas industry. A strong background in physics, including a doctorate for studies of brittle fracture behaviour, provides a firm foundation for understanding hazard and risk analysis techniques and their application to solve practical problems. Mike joined British Gas shortly after the Piper Alpha disaster in the UK North Sea, and immediately became involved in ground-breaking work to understand the explosion and fire hazards offshore, and to identify methods of mitigating the risks. He has since been responsible for major experimental programmes to study jet fire hazards for high pressure gas and other fuels and involved in many large-scale experiments to study the hazards associated with high and low pressure underground pipelines, including full-scale experiments in Canada to study gas transmission pipeline ruptures.

Dr Gary Tomlin

Gary is a Chartered Engineer with over 30 years' experience in the gas industry, working in both the natural gas and LPG market sectors. He has expertise in fire and explosion, gas storage, distribution, utilisation, emergency service provision and the investigation of incidents. Gary manages the DNV GL Spadeadam Testing and Research Centre and has been a member of the DNV GL incident investigation team since 2008, having investigated over 100 fatal and non-fatal gas-related incidents including fire, explosion, BLEVE and carbon monoxide poisoning. In this role, Gary has provided expert support in relation to several incidents in both criminal and civil litigation.

Gary started his career with British Gas, working in both utilisation and distribution, before moving to join CORGI, leading a team assessing the competence of registered gas businesses and installers.

Dan Allason

Dan is a Chartered Physicist with over ten years of experience in major hazard research at DNV GL's Spadeadam Testing and Research Centre. He specialises in large-scale major hazard studies designed to enhance industry knowledge and understanding through the conduct of experiments at or near to full scale. Dan is currently leading the experimental works as part of H21 Phase 1b at Spadeadam, and has a history of involvement with key hydrogen and natural gas research projects

Health and Safety Executive Science Division (HSE-SD)

HSE-SD is one of the world's leading providers of workplace health and safety research, training and consultancy, employing staff across a wide range of disciplines. HSE-SD have been developing health and safety solutions for over 100 years and have a long track record in hydrogen experiments, both in nuclear applications and the safe use of hydrogen as a new fuel. At their Buxton site, they have developed considerable expertise in safely carrying out testing to establish baseline measurements, as is required within this programme of work.

Input into Regulations, Codes and Standards: Over the last 15 years HSE-SD has undertaken and been part of a major experimental and research programme into the hazards and risks associated with retailing hydrogen. Since 2004, through Dr Stuart Hawksworth, HSE-SD has represented the UK on the International Energy Agency Hydrogen Implementing Agreement Safety Task 37. This is a network of hydrogen experts from all over the world whose overall goal is to reduce or eliminate safety-related barriers to widespread commercial adoption. HSE-SD is also a member of the International Association for Hydrogen Safety (IAHS HySafe) and was a founding member of the HySafe Network of Excellence in 2004.

Catherine Spriggs

Catherine has over 15 years' experience of working on complex projects in the business, science and construction sectors, varying in value from tens of thousands of pounds to hundreds of millions of pounds. She joined the HSE-SD in 2012 and works in the Major Hazard team, managing scientific research projects for commercial clients predominantly in the energy, defence and aerospace sectors. Catherine contributes to a significant proportion of the GB hydrogen-based projects and is therefore well placed to advise on potential duplication of work or scope.

Phil Hooker

Phil has spent 25 years in the process industry in various technical roles including process technology, quality and, for the last 10 years, in process hazards. Since joining HSE-SD in 2009 Phil has been involved in hydrogen research including ignition by corona discharges, spontaneous ignition due to releases from pressurised storage, the behaviour of liquid hydrogen spills, and the dispersion, deflagration and jet fire characteristics of hydrogen gas in enclosures. Phil was a contributing author of the HSE Research Report HSE RR1047 on hydrogen addition to natural gas.

Leeds Sustainability Institute at Leeds Beckett University

The Leeds Sustainability Institute (LSI) at Leeds Beckett University is a team of academics and practitioners with over 20 years' experience of research and consultancy in sustainable energy use. The team includes psychologists, data scientists, environmental scientists, architects, design specialists, construction managers, and building performance researchers. In addition, the LSI hosts PhD and Engineering Doctorate students, the majority of whom come from leading organisations in the UK energy and construction sectors. The LSI has an excellent track record of working on national projects on energy-related projects and behaviour change. It has secured over £3 million in energy-related research over the last five years, mainly focusing on energy use in homes and the socio-technical factors that result in technologies and solutions not achieving their projected benefits. LSI projects are commissioned mainly from Government departments, Innovate UK, research councils and directly from industry.

Dr Fiona Fylan

Fiona is a health psychologist who specialises in research to understand and change behaviour that improves health and wellbeing and increases sustainability. She has worked in areas such as energy use, transport choices, healthcare provision and social projects to support vulnerable members of society. Her work on sustainable behaviour includes the public, construction managers and contractors, manufacturers, project commissioners and landlords. Over the last 10 years Fiona has led more than 50 research projects across a range of applied health psychology topics and has attracted over £2 million of research funding. She specialises at leading complex projects involving multiple stakeholders and projects that need to deliver actionable insight and understanding. Fiona led the Phase 1 social research on the public understanding and acceptance of hydrogen as a domestic fuel. Fiona undertakes research for a range of clients including government, local authorities, charities and commercial organisations.

Appendix J. Stakeholder engagement

Key to Stakeholder Group: International (I), Regulatory Body (RB), Local & Regional Government (LA), National Government (GOV), Wider Utilities (WU), Domestic business connections & their representatives (DOM), Financial Investors (FI), Energy Industry (EI), National Universities, Research Companies and Educational Bodies (RE), Internally (Int), Media (M).

Date	Key Stakeholder Presentations/Conferences	Stakeholder
2018/19	• H21 Project Update and future hydrogen strategy • Presentations at conferences and local stakeholders • COP24 Conference • Low Carbon Network Innovation conference • LCNI Conference • Utility Week Live: Future of Gas conference	Ofgem IGEM Hy4Heat Leeds CC WYCA CCC ENA
Date	**Key Stakeholder Meetings**	**Stakeholder**
	• APPG • Hydrogen Transformation Group • Hydrogen Coordination Group	
Date	**Engagement Method and Activity**	**Stakeholder**
Apr-18	**Workshops:** Working Group Session looking at the Industrial Challenge Strategy Fund and a submission for the fund being made by the UKHFCA	(EI) (WU)
Apr-18	**Industry Forum:** Presentation to the Centrica Regulation Department on H21	(DOM)
May-18	**Other:** Speaker at the KTN Leeds event - 'Unlocking the Potential of Green Gas'	(EI) (WU)
May-18	**Teleconference:** 'Friends of the Earth'	(LA) (GOV)
May-18	**Teleconference:** Venezia Impianti SRL	(I)
Jun-18	**Teleconference:** Representatives of the gas industry and government of Canada to discuss the H21 project and the utilisation of hydrogen in decarbonisation of the gas grid	(EI) (WU) (I)
Jun-18	**Teleconference:** BNP Paribas (Suisse) to discuss the H21 project and their hydrogen initiative ambitions	(EI) (WU) (I)
Jun-18	**Teleconference:** Newcastle University to input into their Research and Innovation Infrastructure Roadmap	(RE)
Jul-18	**Meeting:** Andrew Lawrence to discuss H21 NoE	(EI)
Jul-18	**Forum:** Attending the Hydrogen APPG	(LA) (GOV).
Jul-18	**Presentation:** Speaker at Westminster EE&T Forum: Future of the UK Gas Network	(LA) (GOV).
Jul-18	**Forum:** Attended the UK HFCA Executive Meeting	(EI)
Jul-18	**Meeting:** OGE (a German Gas Company) to discuss the H21 project and its learnings	(EI)
Jul-18	**Teleconference:** Discussed hydrogen with Aditya Doshi	(EI)

Jul-18	**Teleconference:** Uni of Nottingham to discuss research and skills gaps and Centres for Doctoral Training	(RE)
Jul-18	**Teleconference:** Eurogas to discuss the various H21 projects in detail	(EI) (I)
Jul-18	**Meeting:** To agree the terms of reference for the Hy4Heat Coordination Group	(LA) (GOV)
Aug-18	**Meeting:** GRTgaz for a learning expedition on hydrogen in England	(EI) (I)
Sep-18	**Conference Event:** Speaker; Electrification of Fuels: Hydrogen session at the IRENA Innovation conference	(EI) (I) (GOV)
Oct-18	**Meeting:** SIT gas to discuss H21	(EI)
Oct-18	**Conference Event:** Speaking at the Low Carbon Network Innovation conference	(EI)
Nov-18	**Conference Event:** Speaker at the ELEGANCY Conference in Brussels about the H21 project	(I) (EI)
Nov-18	**Teleconference:** Decarbonised Gas Alliance to discuss a CCC zero carbon economy call for evidence	(RB) (EI)
Nov-18	**Meeting:** Roger Harriban - BBC to discuss the H21 NoE project	(M)
Nov-18	**Meeting:** Lord Fox - Shadow Lib Dem cabinet member for BEIS to discuss the H21 NoE report	(GOV)
Nov-18	**Meeting:** Lord Randall - Energy Advisor to the Prime Minister to discuss the H21 NoE report	(GOV)
Nov-18	**Interview:** Tom Parmenter at Sky News about the H21 NoE project	(M)
Nov-18	**Roundtable Event:** Network Magazine and NG event on 'Solving future system challenges now'.	(EI) (RB) (RE)
Jan-19	**Conference Event:** Speaker at the Norwegian Petroleum Society conference. Gave H21 project update.	(I) (EI)
Jan-19	**Meeting:** Newcastle University to discuss CESI Control rooms of the future - new project to research the potential beneficial interactions between gas and electricity control centres	(RE)
Jan-19	**Meeting:** City of Bradford Council to update on the H21 project and explore possible knowledge transfer and future collaboration	(LA)
Jan-19	**Teleconference:** Decarbonised Gas Allowance to discuss their future strategy	(RB) (EI)
Jan-19	**Teleconference:** DBI, a German Research company who have conducted hydrogen for heat research, in order to share knowledge	(I) (RE) (EI)
Jan-19	**Teleconference:** European Investment Bank to develop their understanding of hydrogen research to improve their future investment strategy	(I) (FI)
Jan-19	**Meeting:** Attended the West Yorkshire Combined Authority's Green Economy Panel and delivered an update on the H21 project	(LA)

Jan-19	**Conference Event:** Speaker at the SuperGen conference on both the InTEGReL and H21 projects alongside narratives on other UK hydrogen projects	(EI)
Feb-19	**Conference Event:** Speaker at the HSE Future of Gas Series II conference. Presented updates on H21 and InTEGReL	(RB) (EI) (RE)
Feb-19	**Meeting:** North East Local Enterprise Partnership Energy Programme Lead	(LA)
Feb-19	**Meeting:** Northern Powerhouse	(LA)
Feb-19	**Meeting:** Horsebridge to discuss the evolution of gas network infrastructure	(EI) (M)
Feb-19	**Meeting:** Amy Salisbury (BEIS)	(GOV)
Feb-19	**Meeting:** Chief Scientific Advisor to Australia to inform his team about the H21 project	(I)
Feb-19	**Conference Event:** Speaker at the EvoNorth event - giving an update on H21	(RE)
Feb-19	**Workshop:** Attended the Energy Innovation Needs Assessment workshop on innovation spending priorities on Smart systems	(EI) (GOV)
Mar-19	**Meeting:** Gas regulator of Singapore and Hy4Heat to discuss the hydrogen projects happening in the UK	(I) (GOV)
Mar-19	**Meeting:** Singapore Gas regulator and BEIS Heat4Heat team to discuss Singapore converting to hydrogen	(GOV)
Mar-19	**Workshop:** Attended Policy Connect's Hydrogen roundtable event	(EI) (RE)(GOV)
Mar-19	**Meeting:** Northern Hydrogen Network to discuss progress, actions and agenda re: Hydrogen Corridor	(EI) (RE) (LA)
Mar-19	**Teleconference:** Sunfire to discuss our respective hydrogen projects and establish a knowledge sharing	(EI) (I)
Mar-19	**Teleconference:** DBI Gas to discuss our respective hydrogen projects and establish a knowledge sharing	(EI) (I)
Mar-19	**Meeting:** Attended the Gas Futures Group meeting	(EI)
Mar-19	**Meeting:** Attended the Supergen Energy Networks Hub Industry Advisory Committee meeting	(EI)
Mar-19	**Presentation:** On the H21 project at Green Drinks Leeds	(RE)
Mar-19	**Workshop:** Attended China WS4 Open Networks forum workshop - work with the Power sector on DSO function development and thinking	(EI)
Apr-19	**Teleconference:** BEIS to discuss their hydrogen supply programmes and the H21 project	(EI) (GOV)(RE)
Apr-19	Workshop: Presented update on the H21 project at the Low Carbon Strategy for a workshop organised by Local Authorities in 7 areas	(LA)
Apr-19	**Teleconference:** Christophe Wagner to discuss Energy Futures	(EI)
Apr-19	**Presentation:** Update on the H21 project at the Leeds CC Affordable Warmth Partnership	(LA)

Apr-19	**Meeting:** Peta Ashworth (Australian Social Scientist working with AGIG) to discuss the H21 project and general hydrogen projects taking place in the UK and Australia, and social science aspects of these projects	(EI) (I)
Apr-19	**Meeting:** NE Energy Innovation Partnership	(LA) (RE) (EI)
Apr-19	**Teleconference:** AGIG to discuss our respective hydrogen projects and establish a knowledge sharing	(I) (RE) (EI)
Apr-19	**Meeting:** University of Leeds to discuss hydrogen	(RE)
Apr-19	**Teleconference:** Reviewed the IET, IGEM paper on the future of energy	(RE)
Apr-19	**Meeting:** Gateshead Council members	(LA)
Apr-19	**Workshop:** TVCA, Arup, SembCorp to discuss Hy4Heat, H21 and the future hydrogen economy	(RE)
Apr-19	**Workshop:** Attended Smart Communities Workshop with Enzen, Newcastle University and Newcastle Council	(EI) (RE) (LA)
Apr-19	**Meeting:** Barry Gardiner MP	(GOV)
May-19	**Presentation:** Institute of Directors Breakfast Briefing	(EI)
Mar-19	**Meeting:** Gateshead Business Development team	(LA)
May-19	**Meeting:** Tees Valley Combined Authority	(LA)
May-19	**Meeting:** Joe Doleschal-Ridnell, Investment Director, Office of the Agent General, Government of South Australia	(I)
May-19	**Meeting:** British Steel, TVCA and South Tees Development Corporation to discuss the possibility of collaborating on future projects	(EI) (LA)
May-19	**Conference Event:** Presented on H21 and wider themes at the Utility Week Live: Future of Gas conference	(EI)
May-19	**Presentation:** At the Sustainability in Leeds event	(EI) (LA)
Jun-19	**Workshop:** Attended SGNs Hydrogen End to End event	(EI)
Jun-19	**Conference Event, Workshop:** Presented at IGEM Hydrogen - taking control of your future event	(EI) (RB)

Appendix K. Letters of Support

Date
20/06/2019

Cadent Gas Limited
Brick Kiln Street, Hinckley
Leicestershire LE10 0NA
cadentgas.com

David Gill
Head of Customer Energy Solutions
1100 Century Way
Thorpe Park Business Park
Colton
Leeds LS15 8TU

Cadent
Your Gas Network

Dear David,

H21 program – Letter of Support request

I can confirm support from Cadent for the H21 Phase 2 innovation bid.

The UK, as with most other countries around the world, recognises the challenge of climate change to achieve net zero by 2050. This one of the biggest technical, economic, social and business challenges facing UK today and we fully support the work the H21 project is carrying out and specifically support the next phase of the project to deliver 'quantitative safety evidence' is crucial and will be a significant contribution to the raod to zero.

We believe the objective of the H21 programme Ofgem Network Innovation Competition (NIC) bid for network operations is compelling and a critical step in achieving the 100% hydrogen across the gas networks.

Damien Hawke
Director of Future Networks
Safety & Network Strategy

Cadent Gas Limited
Registered Office Ashbrook Court, Prologis Park
Central Boulevard, Coventry CV7 8PE
Registered in England and Wales No.10080864

National Gas Emergency Service
0800 111 999* (24hrs)
*Calls will be recorded and may be monitored

5000419 (01/13) Page 1 of 1

The Voice of the Networks

ena energynetworks association

Mr Mark Horsley
Chief Executive
Northern Gas Networks
100 Century Way
Thorpe Business Park
Leeds
LS15 8TU

11 July 2019

Dear Mark

Letter of support for H21 Phase 2

I am writing to confirm ENA's support for the H21 Phase 2 innovation bid.

The UK, as with most other countries around the world, recognises the challenge of climate change and has set an ambitious target to achieve net zero by 2050. This is one of the biggest technical, economic, social and business challenges facing the UK today and we fully support the work the H21 project is carrying out. The next phase of the project to deliver 'quantitative safety evidence' is crucial and will be a significant contribution to the road to net zero.

The objectives of the H21 programme bid to the Ofgem Network Innovation Competition (NIC) are compelling and would be a critical step in achieving 100% hydrogen across the gas networks, as part of the collective vision set out in the Gas Decarbonisation Pathways project.

ENA looks forward to continuing to work with NGN and the H21 project partners to support this important work.

Yours sincerely,

David

David Smith
Chief Executive

Energy Networks Association (ENA) represents the companies that operate and maintain the gas and electricity grid network in the UK and Ireland. Serving over 30 million customers, they are responsible for the transmission and distribution network of "wires and pipes" that keep our lights on, our homes warm and our businesses running. Our energy networks have a strong track record of safely and securely providing the UK with the gas and electricity it needs, all whilst delivering for customers and the UK economy.

Energy Networks Association 4 More London Riverside, London SE1 2AU
T +44 (0)20 7706 5100 E info@energynetworks.org W www.energynetworks.org Follow us on Twitter @EnergyNetworks
Energy Networks Association Ltd is a company registered in England & Wales. No. 04832301

HHIC
HEATING & HOTWATER INDUSTRY COUNCIL

16/07/2019

Dear Mark

I can confirm support from HHIC for the H21 Phase 2 innovation bid.

The UK, as with most other countries around the world, recognises the challenge of climate change to achieve net zero by 2050. This one of the biggest technical, economic, social and business challenges facing UK today and we fully support the work the H21 project is carrying out and specifically support the next phase of the project to deliver 'quantitative safety evidence' is crucial and will be a significant contribution to the road to zero.

We believe the objective of the H21 programme Ofgem Network Innovation Competition (NIC) bid for network operations is compelling and a critical step in achieving the 100% hydrogen across the gas networks.

Yours sincerely,

Stewart Clements
Director

HHIC is a division of the Energy and Utilities Alliance (EUA). A company limited by guarantee and registered in England. Company number: 10461234. VAT number: 254 3805 07. Registered address: Camden House, Warwick Road, Kenilworth, Warwickshire, CV8 1TH.

T: +44 (0)1926 513777 F: +44 (0)1926 511923 E: info@hhic.org.uk W: www.hhic.org.uk

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Mark Danter
Senior Project Manager – H21
Northern Gas Network
1100 Century Way
Thorpe Park Business Park,
Leeds LS15 8TU

IGEM
Institution of Gas Engineers & Managers

15th July 2019

RE: H21 Phase 2 Innovation Bid.

Dear Mark,

The Institution of Gas Engineers & Managers (IGEM) is a chartered professional body, licensed by the Engineering Council which serves the wide range of professionals in the UK and the international gas industry through Membership, events and a comprehensive set of Technical Standards.

We recognise that the UK has committed to reducing greenhouse gas emissions by net zero by 2050 and IGEM believes that this can best be achieved by using and decarbonising our gas grid. Decarbonisation by the injection of a hydrogen can be part of a critical and significant pathway to achieving this target. This is one of the biggest technical, economic, social and business challenges facing UK today. IGEM fully support the work the H21 project is carrying out and specifically support the next phase of the project to deliver 'quantitative safety evidence' which is crucial and will be a significant contribution to the road to zero.

We believe the objective of the H21 programme Ofgem Network Innovation Competition (NIC) bid for network operations is compelling and a critical step in achieving the 100% hydrogen across the gas networks.

IGEM works closely with all the gas distribution networks to support their innovation projects. In particular, we understand that NGN are seeking to undertake this project to enable the decarbonisation of the gas grid. We understand the key focus of this work will be to establish the evidence base to support this transition. We believe that this project is of critical importance to the future of the UK gas grid. The practical demonstration of the impacts of hydrogen on the network will provide empirical data which is an essential pre-requisite to enable wider deployment of this low carbon solution.

IGEM is supportive of this work as recent studies that have been commissioned demonstrate that decarbonising the gas grid can play a significant role in meeting our carbon reduction targets.

We look forward to seeing this project develop and the conclusions it reaches.

Yours sincerely,

Ian McCluskey BEng, CEng, FIMechE, FIGEM
Head of Technical and Policy

Institution of Gas Engineers & Managers
IGEM House, 26 & 28 High Street
Kegworth, Derbyshire DE74 2DA

t: +44 (0)1509 678 150
e: general@igem.org.uk
www.igem.org.uk

Registered Charity No. 214011

nationalgrid

National Grid House
Warwick Technology Park
Gallows Hill
Warwick
CV34 6DA

Email only:

Date: 26 June 2019
Ref:

Dear Sir/Madam

H21 Programme

I can confirm support from National Grid Gas Transmission for the H21 Phase 2 innovation bid.

The UK, as with most other countries around the world, recognises the challenge of climate change to achieve net zero by 2050. This one of the biggest technical, economic, social and business challenges facing UK today and we fully support the work the H21 project is carrying out and specifically support the next phase of the project to deliver 'quantitative safety evidence' is crucial and will be a significant contribution to the road to zero.

We believe the objective of the H21 programme Ofgem Network Innovation Competition (NIC) bid for network operations is compelling and a critical step in achieving the 100% hydrogen across the gas networks.

Yours faithfully

Stuart Gregg MSc CEng MSOE
Innovation Manager
Gas Transmission
nationalgrid

+44 (0) 7976360193
stuart.gregg@nationalgrid.com

National Grid is a trading name for:
National Grid UK Ltd
Registered Office: 1-3 Strand, London WC2N 5EH
Registered in England and Wales, No 4508773

Netbeheer Nederland

Netbeheer Nederland
Anna van Buerenplein 43
2595 DA Den Haag

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070 205 50 00
secretariaat@netbeheernederland.nl
netbeheernederland.nl

Northern Gas Networks
Mr. Gill

1100 Century Way
Thorpe Park Business Park Colton
Leeds LS15 8TU
United Kingdom

Reference
BR-2019-1642
Date
17 juli 2019

Name
Carine van Ravesteijn
E-mail
cravesteijn@netbeheernederland.nl

Telephone
070 205 50 00

Subject
Supportletter Next phase H21

Dear Mr. Gill,

Hereby I confirm support from Netbeheer Nederland for the H21 Phase 2 innovation bid.

We recognize the challenge of climate change to achieve net zero emissions by 2050. This is one of the biggest technical, economic, social and business challenges facing us today. We fully support the work the H21 project is carrying out and specifically support the next phase of the project to deliver 'quantitative safety evidence'. The similarities between the gas infrastructure in the UK and The Netherlands make this project very relevant for The Netherlands and we believe the outcome of this project will be critical in gaining knowledge about hydrogen energy infrastructures and a crucial step in achieving 100% hydrogen across gas networks.

We believe that the objective of the H21 programme Ofgem Network Innovation Competition (NIC) bid for network operations will contribute significantly to the road to zero emissions.

Yours sincerely,

André Jurjus
Director

IBAN NL51 ABNA 0613001036
BTW-nummer NL8185.25.101.B01
KvK-nummer 09175117

PROJECT ROME
Commercial Strategy & Communications

24th June 2019

I can confirm support from Project Rome for the H21 Phase 2 innovation bid.

The UK, as with most other countries around the world, recognises the challenge of climate change to achieve net zero by 2050. This one of the biggest technical, economic, social and business challenges facing the UK today and we fully support the work the H21 project is carrying out and specifically support the next phase of the project to deliver 'quantitative safety evidence' is crucial and will be a significant contribution to the road to zero.

We believe the objective of the H21 programme Ofgem Network Innovation Competition (NIC) bid for network operations is compelling and a critical step in achieving the 100% hydrogen across the gas networks.

Regards

Simon Pringle
Managing Director, Project Rome

Visiting Professor, University of Chester

Platform, New Station Street, Leeds LS1 4JB
Company Registration No: 08880701

TEES VALLEY COMBINED AUTHORITY | TEES VALLEY MAYOR

Mark Danter

Senior Project Manager – H21

Northern Gas Networks
1100 Century Way
Thorpe Park Business Park
Colton
Leeds
LS15 8TU

Dear Mark

I am writing to confirm that Tees Valley Combined Authority fully support the H21 Phase 2 innovation bid.

As you are aware, the Tees Valley aspires to become the UK's first Net Zero industrial cluster and our vision includes local production of decarbonised or blue hydrogen as an alternative to Natural Gas, which we very clearly see as one of the UK's key future energy vectors and necessary to deliver 'net zero by 2050', which is one of the biggest technical, economic, social and business challenges facing the UK today.

As such, we firmly believe that the objectives of the H21 programme Ofgem Network Innovation Competition (NIC) bid for network operation trials are compelling and critical steps in the UK's journey towards achieving the use of 100% hydrogen across the gas networks and thus we fully support moving to the next phase of the project to deliver the necessary 'quantitative safety evidence'.

Best Wishes

Alison

Alison Fellows
Investment Director

Cavendish House, Teesdale Business Park,
Stockton-on-Tees, Tees Valley, TS17 6QY
Switchboard: 01642 524400
www.teesvalley-ca.gov.uk

TeesValleyCA

Tees Valley Combined Authority. Registered Address: Cavendish House, Teesdale Business Park, Stockton-on-Tees, Tees Valley, TS17 6QY ofgem

RIIO NIC NETWORK INNOVATION COMPETITION

Australian Gas Networks

Australian Gas Networks Limited
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Adelaide, SA 5000 Australia
PO Box 6468, Halifax Street,
SA 5000 Australia
+61 8 8227 1500
info@australiangasnetworks.com.au
australiangasnetworks.com.au

Wednesday, 24 July 2019

Dear Mr Horsley,

Australian Gas Networks Limited (AGN) is one of Australia's leading gas infrastructure businesses. AGN, together with its sister companies Dampier to Bunbury Pipeline and Multinet Gas, own over 4,000 kilometres of transmission pipeline and 34,000 kilometres of natural gas distribution networks which serve more than 2 million customers. We are active across the country with assets in Victoria, South Australia, Western Australia, Queensland, New South Wales and the Northern Territory.

We fully supports the H21 Phase 2 innovation bid. Whilst work on gas network decarbonisation is underway in Australia, it is at an earlier stage than the United Kingdom (UK), and to this extent, AGN and the wider Australian energy industry closely follows the leading work being carried out in the UK.

AGN is in a similar phase with our hydrogen program, recently launching our Hydrogen Park South Australia (HyP SA) project to the South Australian community (see Attachment 1). This project will supply a 5% renewable hydrogen blended gas to a sectionalised part of our South Australian gas distribution network by mid-2020. Concurrently, we are engaging with industry and research organisations on appliance safety and other network studies regarding the safe handling and combustion of hydrogen blended natural gas delivered via our network assets.

We appreciate the close relationship we have with our UK counterparts and the contact and knowledge sharing activities undertaken. We look forward to hearing about the findings of the Phase 2 innovation program and we are happy to participate, as appropriate, in any initiatives they may be of mutual value in driving best practice in the decarbonisation of natural gas via hydrogen production, blending transportation and storage.

Australia has been driving a lot of change and there is government and industry support within the energy sector for hydrogen taking a strategic role in the mix of decarbonisation solutions. AGN acknowledge that decarbonising the economy is one of the biggest technical, economic, social and business challenges we face and we therefore fully support the work the H21 project is carrying out.

In Australia we are watching the development of the H21 concept with interest and are very supportive of the H21 work programs. We see this as a key requirement to move this opportunity for low/zero carbon energy forward and look forward to seeing how the next phase of the H21 work program progresses.

Yours sincerely,

Craig de Laine
General Manager People and Strategy, Australian Gas Networks

ACN 078 551 685 1

AusNet services

24 July 2019

Locked Bag 14051
Melbourne City Mail Centre
Victoria 8001 Australia
T: 1300 360 795
www.ausnetservices.com.au

Mr M. Horsley
Chief Executive Officer
Northern Gas Networks
1100 Century Way
Leeds LS15 8TU UK

Dear Mark

I can confirm support from AusNet Services for the H21 Phase 2 innovation bid.

The UK, as with most other countries around the world, recognises the challenge of climate change to achieve net zero emissions by 2050. We acknowledge that this is one of the biggest technical, economic, social and business challenges facing society today and we fully support the work the H21 project is carrying out.

Specifically, the key deliverable of the next phase of the project will be to deliver the quantitative safety evidence required to demonstrate the feasibility of network conversion. This will be a key milestone in the H21 work program, which is focused on building the evidence base required to support 100% conversion to hydrogen.

We look forward to seeing how the next phase of the H21 work program progresses.

Yours sincerely,

David Cornsell
Asset Strategy & Planning Manager
For **Joanne Soysa**
General Manager, Gas
AusNet Services
Level 31, 2 Southbank Boulevard
Southbank Victoria 3006 Australia

Tel: (+61) 422 233 356
joanne.soysa@ausnetservices.com.au

AusNet Gas Services Pty Ltd / ABN 43 086 015 036

Your ref
Our ref
File ref

ARUP

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t +44 20 7636 1531
d +44 20 7636 2998
mark.neller@arup.com
www.arup.com

24 July 2019

Dear Sirs,

I can confirm support from Arup for the H21 Phase 2 innovation bid.
The UK, as with most other countries around the world, recognises the challenge of climate change to achieve net zero by 2050. This one of the biggest technical, economic, social and business challenges facing UK today and we fully support the work the H21 project is carrying out and specifically support the next phase of the project to deliver 'quantitative safety evidence' is crucial and will be a significant contribution to the road to zero.

We believe the objective of the H21 programme Ofgem Network Innovation Competition (NIC) bid for network operations is compelling and a critical step in achieving the 100% hydrogen across the gas networks.

Arup has carried out extensive research into the future energy system and is certain there is a strategic role for hydrogen as an energy vector. From the work we have been doing for BEIS as the Delivery Contractor for the Hy4Heat programme, we are confident the safety case for 100% hydrogen distribution networks can be made, and that this NIC submission is a vital step to establishing the evidence to support moving to community trials.

Yours sincerely

Mark Neller
Director

Ove Arup & Partners Ltd | Registered in England & Wales
Registered Number: 1312453 | Registered Address: 13 Fitzroy Street London W1T 4BQ

Energy Networks Australia

Mark Horsley
Chief Executive
Northern Gas Networks, UK

Dear Mark Horsley

Energy Networks Australia is the national industry body representing businesses operating Australia's electricity transmission and distribution and gas distribution networks, with 21 member companies providing more than 16 million electricity and gas connections to almost every home and business across Australia.

Australia, like the UK, is advancing the role of hydrogen to be used as a complementary fuel for gas networks, as a fuel for mobility and to provide support services to electricity supply systems. Our gas distribution networks members are establishing pilot projects to test hydrogen production from renewables and injection in the gas networks.

We are also involved in a new collaborative research organisation – Future Fuels CRC. This CRC has industry participants across the whole gas supply chain from producers, to pipeline operators, gas network operators and gas appliance manufacturers. It is focussing on three programs:

1. Future fuels technologies, systems and markets
2. Networks lifecycle management, and
3. Social acceptance, security of supply and public safety.

The H21 Phase 2 innovation funding bid, by Northern Gas Networks, will complete essential research to inform the safety case for injecting hydrogen into gas networks. I think the successful funding of this project will create significant collaboration and information sharing opportunities between Northern Gas Networks and the innovation projects in Australia, as we move towards injecting 100 per cent hydrogen into networks.

Energy Networks Australia supports the funding bid for Phases 2a and 2b.

If you would like any additional information, please contact Dr Dennis R Van Puyvelde, Head of Gas on dvanpuyvelde@energynetwosk.com.au.

Kind regards,

Andrew Dillon
CEO
24 July 2019

Energy Networks Australia www.energynetworks.com.au
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ABN: 75 106 735 406

Leeds CITY COUNCIL

Mark Horsley
Northern Gas Networks
1100 Century Way
Thorpe Business Park
Colton
Leeds
LS15 8TU

Leeds City Council
3rd Floor
Civic Hall
Leeds LS1 1UR

Our reference: 721/TR/JF

26th July 2019

Dear Mark,

Re: H21 Phase 2 Innovation Bid

I am writing to confirm Leeds City Council's support for the H21 Phase 2 innovation bid.

In September 2018 key stakeholders in the region gathered in Leeds to discuss the progress of H21. The wider benefits and opportunities of the scheme, including to transport and air quality, were the focus of much of the conversation demonstrating the growing appetite to embrace H21 as a truly transformative programme for Yorkshire, the Humber and the North East with its benefits being shared across the whole of the North.

We discussed the importance of embracing the opportunities hydrogen can offer, such as:

- reducing emissions – if the whole UK was to fully convert the gas grid to hydrogen, we could reduce emissions by 30% across an average year; and this is before transport emissions are taken into account;
- skills – creating knowledge and expertise that will be of interest to an international audience, with the UK acting as a global centre of excellence and providing opportunities for our universities and businesses.
- transport – having a developed infrastructure will allow the conversion of trains and buses to run on hydrogen – either directly or through electrification. And, converting other vehicles and fleets could deliver substantial improvements to poor air quality in cities and on major networks.
- jobs – aside from the thousands of high-quality skilled jobs being created as part of the conversion, it is anticipated that the supply chain would be boosted by the establishment of the region as a centre of excellence including through new clusters of innovative industries.

In June 2019, we hosted the UK's first National Hydrogen Summit in Leeds which brought together key stakeholders from academia, industry, government and civil society to identify key challenges and opportunities in a potential move to a hydrogen economy.

Leeds declared a Climate Emergency earlier in 2019 and has identified the potential contribution that hydrogen may play in achieving our low carbon ambitions.

Leeds collaborated productively with NGN in the early stages of H21 and we were pleased to attend the launch of the H21 NIC Buxton Test Facility earlier this month. As the lead local authority for this work we are keen to play an active role in the future development of the project, for which proving the safety case for hydrogen conversion is a critical element.

Leeds City Council has considerable convening power to mobilise relevant partners and promote collaboration and is keen to promote Leeds as a 'Living Lab' where access to city infrastructure can help deliver new innovations that can be scaled; where value is added to accelerate learning, knowledge and implementation. We would seek to add to this contribution through further in kind support in the form of local knowledge, data sets and advice on local policy development and implementation, identifying pilot areas for demonstration projects where appropriate and support the programme in accessing Council partners and stakeholders. We can also host staff at our premises where this would add value to the project.

We look forward to hearing the outcome.

Yours,

Tom

Tom Riordan
Chief Executive

www.leeds.gov.uk general enquiries: 0113 222 4444

Appendix L. Signed NIC bid Acknowledgment Document

Background

A. The parties listed below ("the Parties") are parties to the H21 NIC Phase 2 Bid.

Acknowledgement and Agreement

The parties have submitted this bid on the basis that they agree to provide their 20% share of the mandatory 10% network licencees' contribution towards the NIC bid costs. If the bid is successful, the parties will sign contracting terms based on the arrangements typically adopted for collaborative Network Innovation Allowance projects.

All Parties can confirm their full support and financial commitment to the H21 NIC Phase 2 Bid.

The Parties have signed this Acknowledgement on the date set out below.

Signed by ....

for and on behalf of **NORTHERN GAS NETWORKS LIMITED** Authorised Signatory

Name S. PARKER

Position of Authorised Signatory REGULATION DIRECTOR

Date 1 JULY 2019

Signed by ....

for and on behalf of **CADENT LIMITED** Authorised Signatory

Name Damien Hawke

Position of Authorised Signatory Director of Future Networks

Date 20/06/19

Signed by ....

for and on behalf of **NATIONAL GRID LIMITED** Authorised Signatory

Name S Cresse

Position of Authorised Signatory Innovation Manager

Date 26/6/19.

ofgem

RIIO NIC NETWORK INNOVATION COMPETITION

Background

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All Parties can confirm their full support and financial commitment to the H21 NIC Phase 2 Bid.

The Parties have signed this Acknowledgement on the date set out below.

Signed by ....

for and on behalf of **SGN** Authorised Signatory

Name ANGUS McINTOSH

Position of Authorised Signatory DIRECTOR OF ENERGY FUTURES.

Date 26/6/19

Signed by ....

for and on behalf of **WALES AND WEST UTILITIES LIMITED** Authorised Signatory

Name GRAHAM EDWARDS

Position of Authorised Signatory CEO.

Date 24.07.19.